AD 697 160

STUDIES OF OFF-ROAD VEHICLES IN THE RIVERINE ENVIRONMENT. VOLUME II. AN ANALYTICAL METHOD FOR EGRESS EVALUATION

D. Sloss, et al

Stevens Institute of Technology
Hoboken, New Jersey

October 1969

DAVIDSON LABORATORY

Report 1393

STUDIES OF OFF-ROAD VEHICLES IN THE RIVERINE ENVIRONMENT
Vol. II. An Analytical Method for Egress Evaluation

by

D. Sloss
I. R. Ehrlich
and
G. Worden

Prepared for the
U. S. Army Tank-Automotive Center
under
Contracts DA 30-069-AMC-789(T),
DAAE-07-69-C-0356
and Stevens Internal Research Funds

STEVENS INSTITUTE OF TECHNOLOGY
CASTLE POINT STATION
HOBOKEN, NEW JERSEY

October 1969

67

DAVIDSON LABORATORY

STEVENS INSTITUTE OF TECHNOLOGY
Castle Point Station
Hoboken, New Jersey 07030

Report 1393

October 1969

STUDIES OF OFF-ROAD VEHICLES IN THE RIVERINE ENVIRONMENT
Volume II. An Analytical Method for Egress Evaluation

by

D. Sloss

I. R. Ehrlich

and

G. Worden

Prepared for the
U. S. Army Tank-Automotive Center
under
Contracts DA 30-069-AMC-789(T),
DAAE-07-69-C-0356,
and Stevens Internal Research Funds

(DL Projects 3016, 3516, 3479 / 439, 408, 870)

Approved

I. Robert Ehrlich, Manager
Transportation Research Group

xvii + 49 pages
1 table, 16 figures, 1 appendix

ABSTRACT

A limited computer-simulation model describing the dynamics of a swimming vehicle egressing from a stream is formulated. The effects of soil reactions, hydrostatic forces, suspension and tire dynamics, and auxiliary egress assist forces are considered. Results of a parametric study are presented for a four-wheeled, box-shaped vehicle egressing onto a hard, uniformly sloped bank. Length, freeboard, center of gravity, suspension spring and damping rates, initial velocity, and bank coefficient are varied in the analysis.

A correlation study, which validates the computer simulation model, is also described. Plots of normal wheel-loading versus distance up the bank, showing a comparison between the computer simulation and scale-model tests, are included.

Recommendations for a comprehensive parametric study and a correlation study with full-scale vehicles are made.

KEYWORDS

Vehicle Egress
River Crossings
Mobility
Amphibians
Simulation
Floaters
Swimmers
Riverine Environment
Off-Road Vehicles

CONTENTS FOR VOLUME II

(Cont'd)

Contents for Volume II (Cont'd)

LIST OF FIGURES

FOREWORD TO VOLUMES I, II, AND III
of
STUDIES OF OFF-ROAD VEHICLES IN THE RIVERINE ENVIRONMENT

One of the most important considerations in the development of military vehicles has been the recent recognition that to achieve true cross-country mobility a vehicle must possess the inherent capability of crossing inland waterways. This fact has brought a new dimension to the problems confronted by those faced with the responsibility for the design and development of new military vehicle concepts. In order to incorporate this new facet into future designs, it is quite logical to turn for guidance to the designers and developers of amphibious vehicles, who have for some time been confronted by similar problems. It is in this context that the studies discussed in these three volumes were undertaken. Although the purpose of the work was originally intended to aid in the design of $\frac{1}{4}$-ton floating vehicles,[1] the information presented is applicable to land vehicles in general; hence, this document may be considered as a guide to methods for evaluating all types of land vehicles relative to their performance in crossing inland waterways.

There are two distinct aspects of vehicle evaluation:

(1) First, it is necessary to determine functional relationships between the vehicle and its environment so that its performance capabilities may be expressed in quantitative form.

(2) Second, to determine the vehicle's actual effectiveness, it is then necessary to compare these performance capabilities with appropriate quantitative environmental attributes of the inland waterway population (or some sub-set thereof of military interest). In view of the present state of knowledge in vehicle mechanics and environmental sciences, the attainment of these objectives represents a tremendous task. The work presented in this report constitutes a compendium of much of the applicable knowledge in this area, with progress naturally more advanced in some areas than others, and it provides, moreover, a meaningful conceptual

framework for continued work by indicating the knowledge gaps that exist.

Three different modes of locomotion are important in connection with the general stream-crossing maneuver: fully floating, fully land-borne, and water-land transition. Of equal importance are the associated environmental factors relevant to all three modes.

At its inception, this study was designed to concentrate most heavily on various aspects of the fully floating mode,[2] and much of the effort was directed toward the development of vehicle-environment relationships for the fully floating case. Major consideration has been given to such factors as hydrodynamic resistance, propulsion effectiveness, freeboard requirements, and the effects of waves. These are areas in which a sophisticated technology has already been developed by the naval architect,[3,4] but where applications to the design and evaluation of amphibious vehicles or ships having vehicle-like forms have been extremely limited. As the work progressed, however, it became increasingly clear that by far the most critical element of the stream-crossing maneuver was egress. The study of egress is therefore of prime practical importance.

This water-land transition aspect of stream-crossing is a subject about which very little is known. Analysis of this "twilight zone" is extremely complicated, involving consideration of both hydrodynamical and terramechanical factors. Many actual field problems, however, have demonstrated that the transition phase, particularly egress, is usually the most difficult element of the entire stream-crossing maneuver; hence this complication cannot be avoided.

Relationships between the fully land-borne vehicle and its environment (terrain) have been under intensive investigation for many years,[5,6,7,8] notably under the auspices of the U. S. Army. The task of particularizing the previously developed models to the bank environment where the proximity of the stream or river is known to affect the soil and vegetation is beyond the scope of this study.

Another area in which the current efforts represent only a scratch of the surface of the problem is that associated with the determination of environmental attributes. It has become apparent that complete quantification of world-wide stream properties in sufficient detail for vehicle

performance evaluation cannot possibly be achieved by direct measurement within the scope of any reasonable study, nor is the military really interested in the characteristics of every stream in the world. Therefore, an approach toward categorizing waterways on the basis of available climatic, geological, and other existing environmental data has been initiated as part of the study so that those of military interest may be studied.

It is worth repeating here that the present work is by no means regarded as a finished product. Many of the relationships which are presented should be considered as no more than reasonable hypotheses which must be validated and, if necessary, modified on the basis of carefully controlled experiments. Much additional research in the various problem areas and a major effort to coordinate the various facets into a comprehensive systems analysis is required before the kind of evaluation scheme envisioned as the long-term goal of this study can be achieved.

This document (Vol. II) represents a part of the entire multi-part study to which this foreword is an over-all introduction. It is concerned with the water-land transition. Volume I deals with performance afloat, and Volume III with associated environmental factors.

INTRODUCTION TO VOLUME II

The first requisite to the establishment of reliable objective methods of designing and evaluating vehicles for employment in any environment is the development of mathematical models which express relevant vehicle performance characteristics in terms of specific design parameters and appropriate environmental properties. It is in this context that the river-exiting problem is approached.

The total river-crossing problem has been defined as one of moving a vehicle across a river from one dry bank to the other, or, in present terminology, negotiating the riverine environment. The problem has three subdivisions -- ingress, water performance, and egress. This volume of "Studies of Off-Road Vehicles in the Riverine Environment" is primarily concerned with egress. The problem of ingress is considered secondary, as compared with egress, and for this reason receives only limited attention.

The available riverine environmental data[9,10,11,12] suggest that, if relatively large geographic areas are considered (such as the Eastern United States, Thailand, or Western Germany), river egress will be difficult for mobile tracked vehicles in two-thirds to three-fourths of the crossings. This is, of course, only a very gross estimate. Specific areas, such as those near a coast or a delta, will present a much higher level of difficulty and those inland a generally lower level. Exiting is also related to river depth; the greater the depth, the greater the exiting problem. Therefore, if the vehicle has to float instead of ford, the probability of exiting difficulty is increased.*

*In the same stream bed, however, a higher water level, although requiring the vehicle to swim, will frequently reduce the height of the bank that the vehicle must negotiate. This will sometimes make the exiting problem easier.

Exiting is the primary problem in river-crossing because water performance is of value only if the vehicle can negotiate the bank. Water performance, however (particularly speed), can have a significant effect on the vehicle's ability to exit, as will be shown in the parametric analysis appearing in this report. Thus, the two factors are interrelated when the vehicle floats.

NOMENCLATURE FOR VOLUME II

A	area
C	damping coefficient
c	soil cohesion
CB	center of buoyancy
CG	center of gravity
D_i	force of the i^{th} suspension element on the body and wheel
F_A	auxiliary assist force
FB	buoyant force
FS	soil tractive force on wheels
g	gravitational constant
I	polar mass moment of inertia about CG
K	spring constant
K_b	bump-stop spring force
L	total vehicle length
LCG	longitudinal center of gravity location
m	mass
NB	number of body boxes
NW	number of wheels

RR	wheel rolling resistance
r	radius of the tire
T_F	torque supplied to front wheels (ft-lb)
T_R	torque supplied to rear wheels (ft-lb)
WL	waterline
X,Y	inertial coordinates with origin at intersection of waterline and bank; X-axis horizontal, Y-axis vertical
$Y_i, X_i, \zeta_u, \eta_i$	body coordinates (from CG) of the i^{th} location
α	angle of bank from horizontal (angle between ρ- and X-axes)
β	angle between F_A and ζ-axes
$\Delta\rho$	total distance the front wheels of the egressing vehicle travel up the bank before stopping; an index of performance
γ	specific weight of water
λ	spring length
Φ	coefficient of friction between ramp or bank and tires
φ	soil angle of internal friction
θ	body trim angle (angle between ζ- and X-axes)
μ, ρ	inertial coordinates with origin at intersection of waterline and bank; μ-axis normal, ρ-axis tangential to bank
ξ_B	width of body
ξ_t	wheel width (2 tires per axle)

ζ,η body coordinates with origin at body CG; ζ-axis longitudinal

Subscripts

A assist-force properties

B body properties

F front-wheel properties

R rear-wheel properties

i body-box-element property

k wheel property

o undeflected length of spring

r rim property

t tire property

1,3,5 front-suspension and -tire properties

2,4,6 rear-suspension and -tire properties

11,12,13,14 vehicle-body locations

Chapter 1
COMPUTER SIMULATION

In previous attempts to quantify the egress process, a gross measure of vehicle performance (its vertical step-climbing ability) and an empirical measure of the river bank severity (its relative height) were used.[13] The major disadvantage of this method was the degree of limitation on the amount of design analysis which was possible within this framework. A more useful tool, computer simulation of the exiting problem, is developed in this report. The simulation, validated, will permit the examination of many different exiting situations and lead to the development of some more meaningful relationships between the various vehicle and river parameters and the ability of a vehicle to exit.

The entire egress operation is a quite complicated maneuver, and little is known about the interplay of vehicle, water, and land factors. This establishment of an egress computer model is the start of an attempt to sort out these factors. The model is presented here with a description of its capabilities, its potential, and the stage of its development at the conclusion of the study. It is limited in nature and must be considered simply the first cut of a much more sophisticated simulation to follow.

THE VEHICLE

The vehicle is treated as a three-mass system consisting of the body, the front suspension system, and the rear suspension system. The body translates and rotates, but the suspensions are treated as point masses which can only translate. The suspensions are joined to the body by pairs of spring-dashpot connectors, in such a fashion as to make possible the independent specification of horizontal and vertical spring rates (Fig. 1). Between the suspension and the ground is a spring-dashpot to represent the action of the tires. All of the submerged components of the vehicle generate buoyant forces. These forces, balanced against the

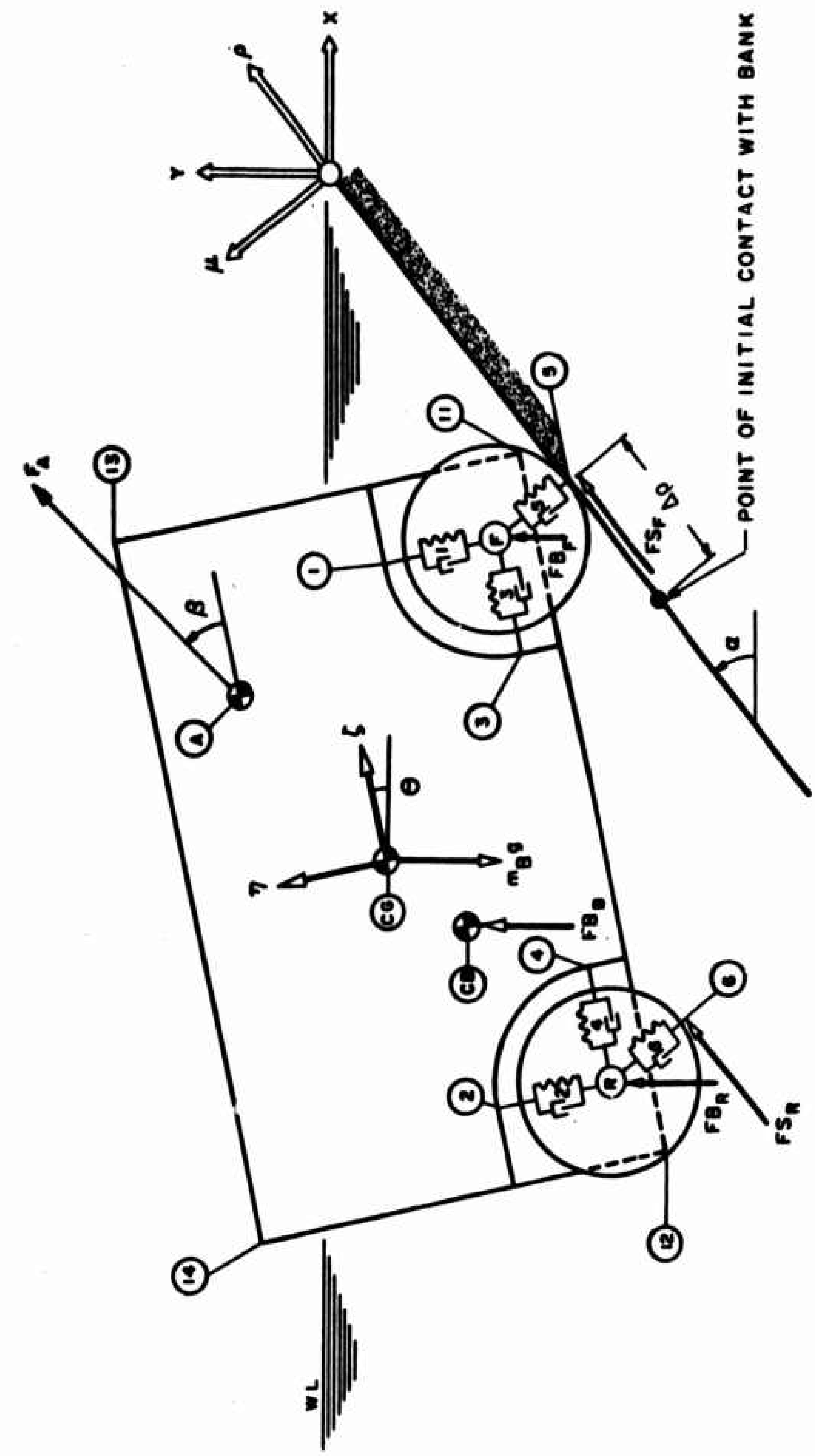


FIGURE 1. Egress Study Model

usual gravitational forces, govern the attitude of the vehicle and the ground contact forces under the various suspension elements. The simulation accepts a vehicle of any general configuration and any number of wheels. In this report, however, only 4x4 and 8x8 vehicles are considered.

THE BANK

The bank is a uniform surface, without steps or breaks in its slope. In the initial studies, surface properties are represented by a single value for the coefficient of friction, but soil properties can be represented by using either the Bekker parameters or an "average rating cone index for one-pass predictions." The soil properties can be varied along the slope to represent changes in strength from below water to dry land.

In the studies discussed here, the bank configuration is restricted to a uniform slope with a hard surface. Existing environmental data indicate that a uniform slope is not the general case for river banks, but banks with relatively uniform slopes and firm soil conditions do comprise about 20 to 30 percent of the banks surveyed. This analysis is therefore representative of some actual environmental conditions.

THE FRAMEWORK OF THE SIMULATION

An amphibian emerges from the water by approaching normal to the shoreline, placing its tires or tracks against the bank, and then proceeding to crawl up and out, under its own power alone or with an assist force. The simulation employed here is two-dimensional with seven degrees of freedom. The initial condition for model representation is a full vehicle, floating and moving toward the shore at some uniform initial velocity. The vehicle is provided with enough thrust to maintain this initial velocity until it strikes the bank; torque is then supplied to the wheels, so that the vehicle can attempt to mount the bank. The simulation provides for an external assist force (winch, rocket, or other) at any

time and at any direction during the exiting maneuver. The simulation carries the vehicle from a fully floating to a fully land-borne condition. It may be terminated at any of a number of pre-set conditions. The relationships between the various parameters placed in the simulation dictate the outcome of the problem. Three possibilities exist: the vehicle climbs up the slope and out of the water (succeeds); the vehicle becomes immobilized on the slope (gets stuck in the mud); or the vehicle rolls back into the water to the full floating condition (cannot negotiate).

The simulation was used for a parametric study of the exiting performance of a 4x4 wheeled vehicle; and the results of the computer simulation were compared with results of scale-model tests performed on an 8x8 wheeled vehicle.[14] The results of these studies are discussed later, in detail.

THE MATHEMATICS OF THE SIMULATION

The model contains three coordinate systems: the vehicle or body coordinates η,ζ ; the bank coordinates μ,ρ ; and the inertial coordinates X,Y . The origins of these systems are shown on Fig. 1. The body coordinates rotate through the angle θ , relative to the inertial coordinates X,Y . Obviously there is no rotation of the bank coordinates μ,ρ relative to the inertial coordinates X,Y . Hence α is a constant for the duration of any given test run. And therefore only the X,Y or μ,ρ coordinates are necessary to solve the problem, although both sets of coordinates are convenient in changing bank angle between runs.

The mathematics which follow are for the 4x4 vehicle depicted in Fig. 1. The actual computer program is somewhat more general.

Body Equations of Motion*

$$m_B \ddot{X}_{CG} = \sin\theta\,(D_1 + D_2) + \cos\theta\,(D_3 - D_4) + F_A \cos(\theta + \beta) \quad (1)$$

$$m_B \ddot{Y}_{CG} = \sin\theta\,(D_3 - D_4) - \cos\theta\,(D_1 + D_2) + FB_B - m_B g + F_A \sin(\theta + \beta) \quad (2)$$

$$I_B \ddot{\theta} = \zeta_1 D_1 - \eta_3 D_3 - \zeta_2 D_2 + \eta_4 D_4 + FB_B\,(\eta_{CB} \sin\theta - \zeta_{CB} \cos\theta)$$

$$+ T_F + T_R + F_A\,(\zeta_A \sin\beta - \eta_A \cos\beta) \quad (3)$$

$$\eta_3 = \eta_F - \eta_1 \quad (4)$$

$$\eta_4 = \eta_R - \eta_2 \quad (5)$$

In these equations, care must be taken in specifying locations, so that those locations below or to the left of the CG are negative. The equations assume that there is vertical motion in the suspension, but little horizontal motion. Tensile forces are positive; compressive forces are negative.

Front Wheels (Fig. 2)

$$m_F \ddot{X}_F = - D_1 \sin\theta - D_3 \cos\theta + D_5 \sin\alpha + FS_F \cos\alpha \quad (6)$$

$$m_F \ddot{Y}_F = + D_1 \cos\theta - D_3 \sin\theta - D_5 \cos\alpha + FS_F \sin\alpha \quad (7)$$

$$T_F = FS_F\, r \quad (8)$$

*Refer to nomenclature on page xv for definition of symbols.

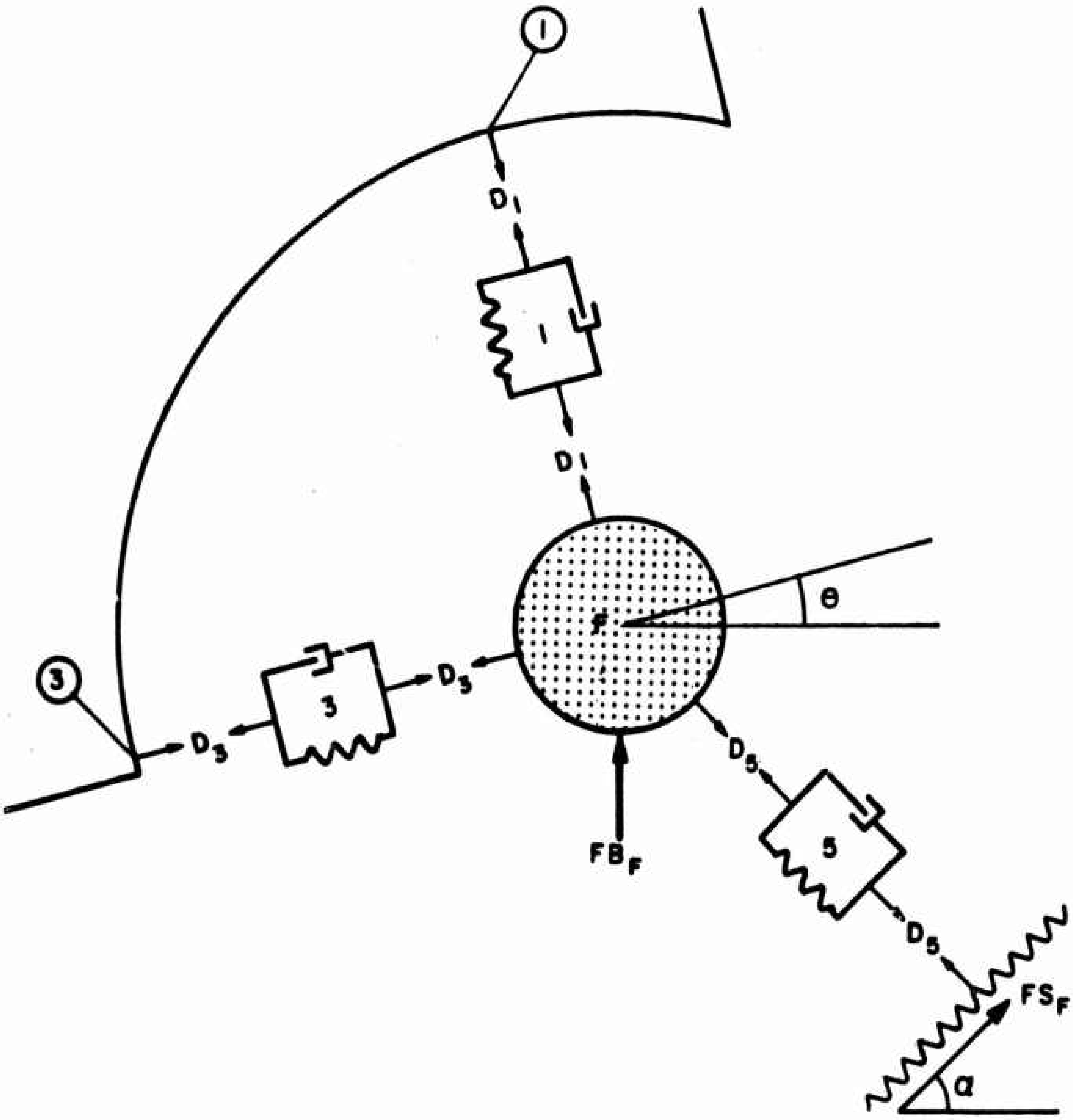


FIGURE 2. Free Body Diagrams of the Front of the Vehicle, the Suspensions, the Wheel, and the Ground

Rear Wheels

$$m_R \ddot{X}_R = D_2 \sin\theta - D_4 \cos\theta - D_6 \sin\alpha + FS_R \cos\alpha \tag{9}$$

$$m_R \ddot{Y}_R = D_2 \sin\theta - D_4 \cos\theta + D_6 \cos\alpha + FS_F \sin\alpha \tag{10}$$

$$T_R = FS_R\, r \tag{11}$$

Suspension Systems

If the deflected length of the spring is λ , then

$$\lambda_1 = \eta_F - \eta_1 \quad ; \quad \lambda_2 = \eta_R - \eta_2 \quad ; \quad \lambda_3 = \xi_F - \zeta_3 \quad ; \quad \lambda_4 = \xi_4 - \zeta_R$$

$$\lambda_5 = (\eta_F - \eta_5) \cos(\alpha - \theta) + (\zeta_5 - \zeta_F) \sin(\alpha - \theta) \quad ; \quad \lambda_5 \leq r$$

$$\lambda_6 = (\eta_R - \eta_6) \cos(\alpha - \theta) + (\zeta_6 - \zeta_R) \sin(\alpha - \theta) \quad ; \quad \lambda_6 \leq r \tag{12}$$

Incorporated in the suspension system is the bump stop on the springs.

$$D_{bi} = K_{bi} (\lambda_i - \lambda_{obi}) \quad ; \quad D_{bi} \leq 0 \tag{13}$$

Then the suspension forces are

$$D_1 = (\lambda_1 - \lambda_{01}) K_1 + \lambda_1 C_1 + D_{b1}$$

$$D_2 = (\lambda_2 - \lambda_{02}) K_2 + \dot{\lambda}_2 C_2 + D_{b2}$$

$$D_3 = (\lambda_3 - \lambda_{03}) K_3 + \dot{\lambda}_3 C_3 + D_{b3}$$

(Eq. cont'd)

$$D_4 = (\lambda_4 - \lambda_{04})\ K_4 + \dot{\lambda}_4 C_4 + D_{b4}$$

$$D_5 = (\lambda_5 - r)\ K_5 + \dot{\lambda}_5 C_5 \quad ; \quad D_5 \leq 0$$

$$D_6 = (\lambda_6 - r)\ K_6 + \dot{\lambda}_6 C_6 \quad ; \quad D_6 \leq 0 \tag{14}$$

Although most automotive shock absorbers have a different damping rate for compression (jounce) and extension (rebound), Eqs. (14) do not reflect that fact.

Tire-Bank Reaction Equations

Two different sets of equations have been written to represent the tire-soil reaction at the bank. Eventually, both will be programmed, and their egress trajectory predictions compared with each other and with corresponding experimental results. One set of tire-soil equations, based on the work of Bekker[5,15] and his former associates at the Land Locomotion Division,[16] employs the familiar Micklethwaite equation for drawbar pull,[17] with soil-compaction resistance calculated by energy-work methods from the Bernstein-Bekker sinkage equation.[5] Soil properties are described in terms of five independently specified parameters: the angle of internal friction (φ), cohesion (c), the pressure-sinkage exponent, and two additional pressure-sinkage moduli.* The second set of soil equations is based on the empirical approach pioneered by investigators at the Waterways Experiment Station[7,20] and extended by Nuttall, Wilson and Werner.[21] In this case, drawbar pull is calculated by use of an empirical equation depending on only two soil parameters -- an "average rating cone index for one-pass predictions" and a surface-shear-strength

*The "independence" of the five soil parameters in the Bekker representation gives rise to much of the severest criticism of this approach. Theoreticians are quick to point out that the sinkage moduli must indeed be related to c and φ; in particular, tha 'e Bekker pressure-sinkage equation should reduce to the form of accepted bearing-capacity theory for low sinkages.[18,19]

parameter, both evaluated from measurements made with the standard WES cone penetrometer and its subsidiary instruments for determining remolding indices.[7] It should be emphasized that the "average rating cone index for one-pass predictions" is not the same as the conventional WES rating cone index. It is equal to the average value of the product of the cone index and a remolding correction factor (also different from the standard WES remolding index), over a range of depth from zero to a critical value depending on tire geometry and load.

The tractive forces FS_F for the front wheel and FS_R for the rear wheel are determined from the bank-tire relationships. For the hard-ramp case discussed in this report, the equations for tractive forces are

$$FS_F = -\Phi D_5$$
$$FS_R = -\Phi D_6 \qquad (15)$$

where Φ = tire-ramp coefficient of friction

A minus sign is used here because D is conventionally in compression and considered negative.

Coordinate Transformation Equations

Coordinate transformation equations are required, to relate vehicle locations expressed in vehicle coordinates (η,ζ) and bank locations expressed in bank coordinates (μ,ρ) to the horizontal coordinate system (X,Y).

$$X_n = X_{CG} - \eta_n \sin\theta + \zeta_n \cos\theta$$

$$Y_n = Y_{CG} + \eta_n \cos\theta + \zeta_n \sin\theta$$

$$\mu_n = Y_n \cos\alpha - X_n \sin\alpha$$

(Eq. cont'd)

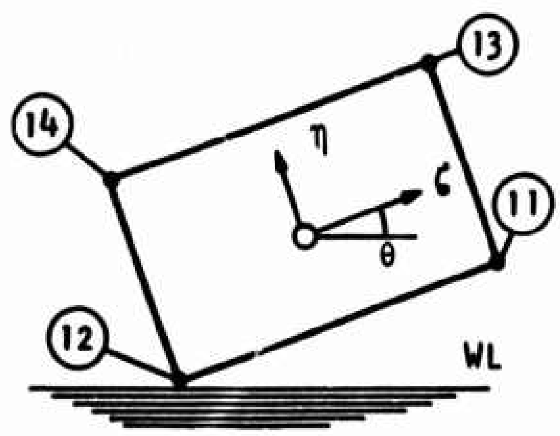
$$\rho_n = Y_n \sin\alpha + X_n \cos\alpha \tag{16}$$

Buoyant Forces

The body equations of motion require both the magnitude (FB_B) and location (η_{CB} , ζ_{CB}) of the buoyant forces on the vehicle body. These values can be generated as a function of the elevation of the center of gravity Y_{CG} , the attitude θ of the body, and the body dimensions. The equations given here are for a simple rectangular box; more complex configurations may be made from an assemblage of rectangles and other simple figures. The six cases given (each case based on whether or not each of the box corners is above or below the waterline) are the only possible combinations for this simulation.

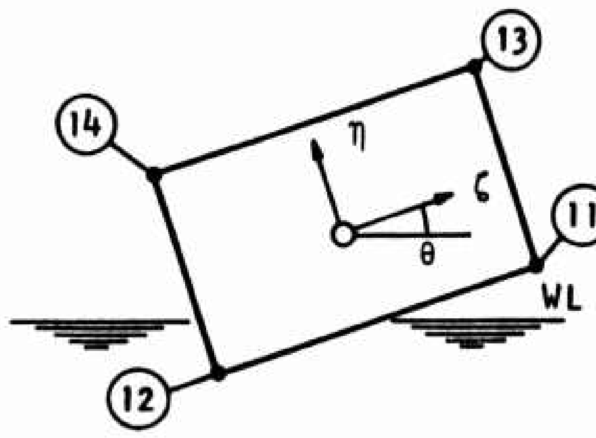
The buoyant force on the wheels , FB_F and FB_R for front and rear respectively, are considered to be constants, acting only when the wheel centers F and R are below the water surface.

CASE 1. Box Completely Out of Water



$$FB_B = 0 \tag{17}$$

Case 2. Lower Left-hand Corner Submerged

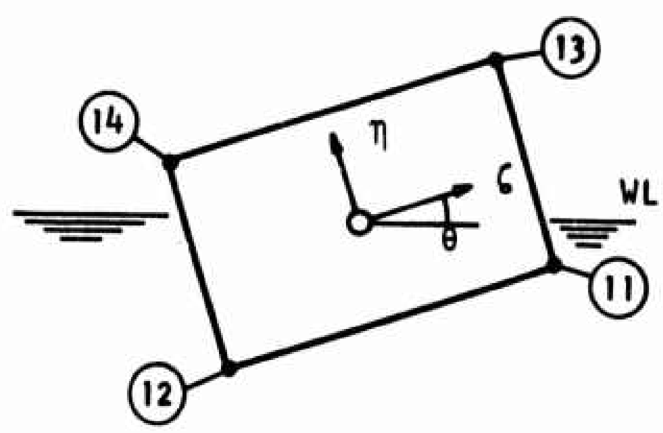


$$FB_B = \xi_B \gamma \frac{Y_{12}^2}{2} \left(\tan\theta + \frac{1}{\tan\theta} \right)$$

$$\eta_{CB} = \eta_{12} - \frac{Y_{12}}{3\cos\theta}$$

$$\zeta_{CB} = \zeta_{12} - \frac{Y_{12}}{3\sin\theta} \tag{18}$$

CASE 3. Lower Two Corners Submerged

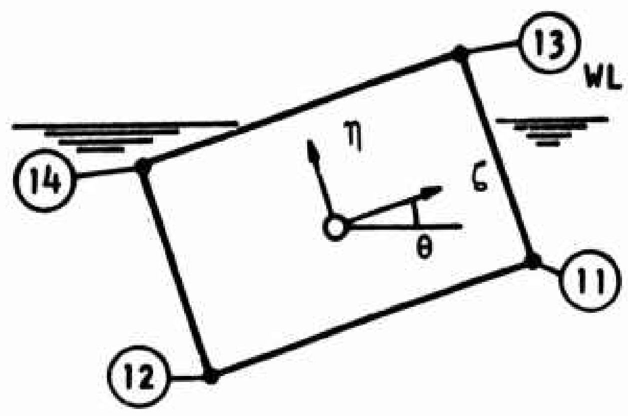


$$FB_B = -\xi_B \gamma (\zeta_{11} - \zeta_{12}) \left(Y_{11} + \frac{Y_{12} - Y_{11}}{2\cos\theta} \right)$$

$$\eta_{CB} = \frac{\left[\eta_{12} + \frac{(\zeta_{11} - \zeta_{12}) \tan\theta}{3} \right] (Y_{12} - Y_{11}) + Y_{11} \left[(\eta_{11} + \eta_{12}) - \frac{Y_{12}}{\cos\theta} \right]}{Y_{11} + Y_{12}}$$

$$\zeta_{CB} = \frac{\left[\zeta_{12} + \frac{(\zeta_{11} - \zeta_{12})}{3} \right] (Y_{12} - Y_{11}) + (\zeta_{11} + \zeta_{12}) \; Y_{11}}{Y_{11} + Y_{12}} \tag{19}$$

CASE 4. All But Upper Front Corner Submerged



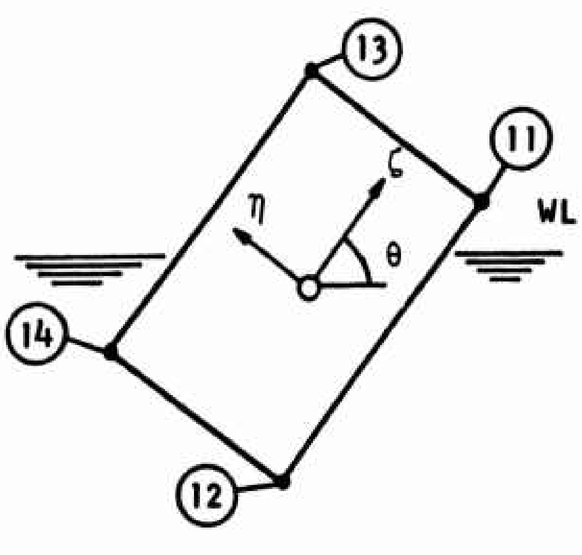
$$FB_B = \xi_B \gamma (\zeta_{11} - \zeta_{12})(\eta_{13} - \eta_{11}) - \frac{Y_{13}^2}{2 \sin\theta \cos\theta}$$

$$\eta_{CB} = \frac{\sin\theta\cos\theta\,(\zeta_{11} - \zeta_{12})(\eta_{13} - \eta_{11})(\eta_{13} + \eta_{11}) - Y_{13}^2\left(\eta_{13} - \frac{Y_{13}}{3\cos\theta}\right)}{2\sin\theta\cos\theta\,(\zeta_{11} - \zeta_{12})(\eta_{13} - \eta_{11}) - Y_{13}^2}$$

$$\zeta_{CB} = \frac{\sin\theta\cos\theta\,(\zeta_{11} - \zeta_{12})(\eta_{13} - \eta_{11})(\zeta_{11} + \zeta_{12}) - Y_{13}^2\left(\zeta_{13} - \frac{Y_{13}}{3\sin\theta}\right)}{2\sin\theta\cos\theta\,(\zeta_{11} - \zeta_{12})(\eta_{13} - \eta_{11}) - Y_{13}^2}$$

(20)

CASE 5. All But Front Two Corners Submerged



CASE 5 (cont'd)

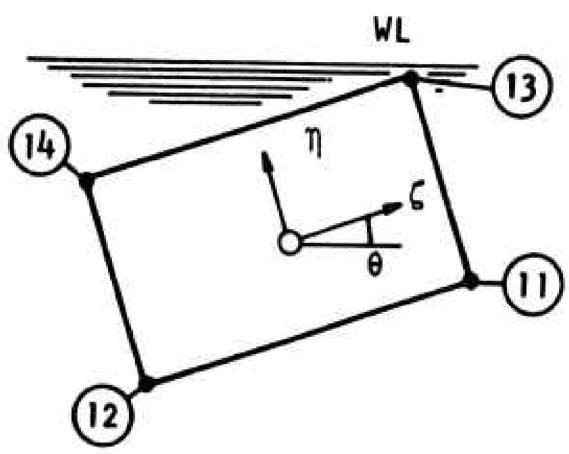
$$FB_B = \xi_B \gamma \left[\frac{(\eta_{14} - \eta_{11})^2}{2 \tan \theta} - \frac{Y_{14} (\eta_{14} - \eta_{12})}{\sin \theta} \right]$$

$$\eta_{CB} = \frac{\frac{(\eta_{14} - \eta_{12})^2 \eta_{12}}{2 \tan \theta} + \frac{\eta_{14} - \eta_{12}}{3} - \frac{Y_{14} (\eta_{14} - \eta_{12})}{\sin \theta} \frac{\eta_{14} + \eta_{12}}{2}}{\frac{(\eta_{14} - \eta_{12})^2}{2 \tan \theta} - \frac{Y_{14} (\eta_{14} - \eta_{12})}{\sin \theta}}$$

$$\zeta_{CB} = \frac{\frac{(\eta_{14} - \eta_{12})^2}{2 \tan \theta} \zeta_{12} + \frac{\eta_{14} - \eta_{12}}{3 \tan \theta} - \frac{Y_{14} (\eta_{14} - \eta_{12})}{\sin \theta} \zeta_{14} + \frac{\eta_{14} - \eta_{12}}{2 \tan \theta} - \frac{Y_{14}}{2 \sin \theta}}{\frac{(\eta_{14} - \eta_{12})^2}{2 \tan \theta} - \frac{Y_{14}(\eta_{14} - \eta_{12})}{\sin \theta}}$$

(21)

CASE 6. All Corners Submerged



$$FB_B = \xi_B \gamma (\eta_{13} - \eta_{11}) (\zeta_{11} - \zeta_{12})$$

$$\eta_{CB} = \frac{\eta_{13} + \eta_{11}}{2}$$

$$\zeta_{CB} = \frac{\zeta_{11} + \zeta_{12}}{2}$$

(22)

Engine Characteristics

The torque-horsepower-rpm characteristics of the engine constrain the performance of the vehicle while it is negotiating the bank. In this simulation, however, the only constraint imposed is that the delivered horsepower and the applied torque are never greater than the maximum that can be delivered by the engine-drive train package.

$$
\begin{aligned}
&2\,(FS_F + FS_R)\,V < HP_{max} \\
&2\,(FS_F + FS_R)\,r < T_{max}
\end{aligned}
\tag{23}
$$

Assist Forces

Various kinds of assisting force can be employed to help the vehicle exit. The magnitude, direction, and extent of this force is an important parameter, requiring investigation. Accordingly, the program allows for the arbitrary application of one or more such forces at any location and at any angle.

Thrust and Drag Forces

It is assumed here that the thrust generated from any propulsive force is equal and opposite to the hydrodynamic drag of the vehicle.

Chapter 2

PARAMETRIC VARIATIONS

The computer simulation model was initially applied to a parametric study of a four-wheeled, box-shaped vehicle egressing onto a uniform rigid bank. The basic configuration was sized to approximate the geometric proportions of a ¼-scale model of a ¼-ton truck (the U. S. Army Jeep). The baseline values of the various dynamic properties of the jeep were scaled down approximately, according to Froude's law. An exception was the longitudinal-suspension-system stiffness. This value was specified unrealistically low and is more representative of a trailing-arm suspension than of the wishbone type used on the jeep. This was done so that reasonably large integration time intervals could be used, and hence computer time reduced.

The design of the parametric study is shown in the table on page 16. Case 1 represents the basic vehicle configuration egressing onto a bank, with a coefficient of friction of 0.35 and with an initial velocity (water speed) of 2 feet per second. The following parameters were then varied about Case 1 (which was used as the central case):

(1) Vehicle length, plus and minus 25 percent

(2) Freeboard (static), plus and minus 50 percent

(3) Vertical CG location, plus 50 percent and minus 100 percent

(4) Horizontal CG location, plus and minus 25 percent and plus and minus 1/6

(5) Suspension vertical spring rate, plus 100 percent and minus 50 percent*

(6) Suspension vertical damping rate, plus 100 percent and minus 50 percent*

*In each calculation, all suspension spring and damping constants were assigned equal values.

EGRESS PARAMETRIC STUDY PLAN - CASES AND RANGE OF PARAMETERS

	Parameter							
Case No.	Length (ft)	Freeboard (ft)	Velocity (ft/sec)	Springs (lb/ft)	CG Vertical (ft)	CG Horizontal (ft)	Coef. Friction	Damping Coef. (lb-sec/ft)
1	4.0	0.333	2.0	1200	0.333	2.0	0.35	100
2	3.0	-	-	-	-	1.5	-	-
3	5.0	-	-	-	-	2.5	-	-
4	-	0.1667	-	-	-	-	-	-
5	-	0.500	-	-	-	-	-	-
6	-	-	1.0	-	-	-	-	-
7	-	-	4.0	-	-	-	-	-
8	-	-	-	600	-	-	-	-
9	-	-	-	2400	-	-	-	-
10	-	-	-	-	0	-	-	-
11	-	-	-	-	0.500	-	-	-
12	-	-	-	-	-	1.662	-	-
13	-	-	-	-	-	2.338	-	-
14	-	-	-	-	-	-	0.300	-
15	-	-	-	-	-	-	0.250	-
16	-	-	-	-	-	-	0.200	-
17	-	-	-	-	-	-	-	50
18	-	-	-	-	-	-	-	200
19	-	-	1.0	-	-	-	0.300	-
20	-	-	1.0	-	-	-	0.250	-
21	-	-	1.0	-	-	-	0.200	-
22	-	-	4.0	-	-	-	0.300	-
23	-	-	4.0	-	-	-	0.250	-
24	-	-	4.0	-	-	-	0.200	-

NOTE: Case 1 is the "central case." Each case is run at each of the 4 ramp angles (20°, 24°, 28°, and 32°). Empty spaces use central-case values (e.g., the length in Case 10 is 4 feet).

(7) Initial velocity, plus 100 percent and minus 50 percent

(8) Bank friction coefficient, many values

Each vehicle parameter was varied above and below the central case, for a reasonably adequate representation. Bank friction coefficient was treated in a different manner; instead of a variation about the central case, values were chosen that related to the bank slope angles in such a way as to make the bank-soil friction coefficient , Φ , equal to or less than the tangent of the bank angle , α . This limitation was imposed so that no vehicle configuration or changes in other parameters would permit the vehicle to proceed indefinitely up the bank.

EFFECT OF VEHICLE LENGTH

Figure 3 presents the effect of vehicle length on exiting capability. All other parameters are kept equal. Therefore vehicle width, which is not an explicit parameter in the two-dimensional analysis, is varied with length to maintain constant values of displacement and mass density.

The measure of exiting capability is $\Delta\rho_{max}$, the maximum distance the front wheels move up the slope from the initial point of contact. This can be a realistic measure, because soil strength tends to increase with distance up the slope.* Thus the farther the wheels move up the slope the greater the probability the vehicle will achieve sufficient traction to exit. Furthermore, all banks are of finite height; hence the configuration that climbs highest has the greatest chance of exiting.[1]

Figure 3 shows that for the stated conditions the longer vehicle has a distinct advantage. The advantage will be greater when the bank slope angle is only a few degrees higher than the bank friction angle; but the advantage will be only slight when the bank slope angle exceeds the bank friction angle by 50 percent or more. A longer vehicle can have an additional advantage if auxiliary water propulsion is used. The thrust

*See Figure B-4 of Reference 22.

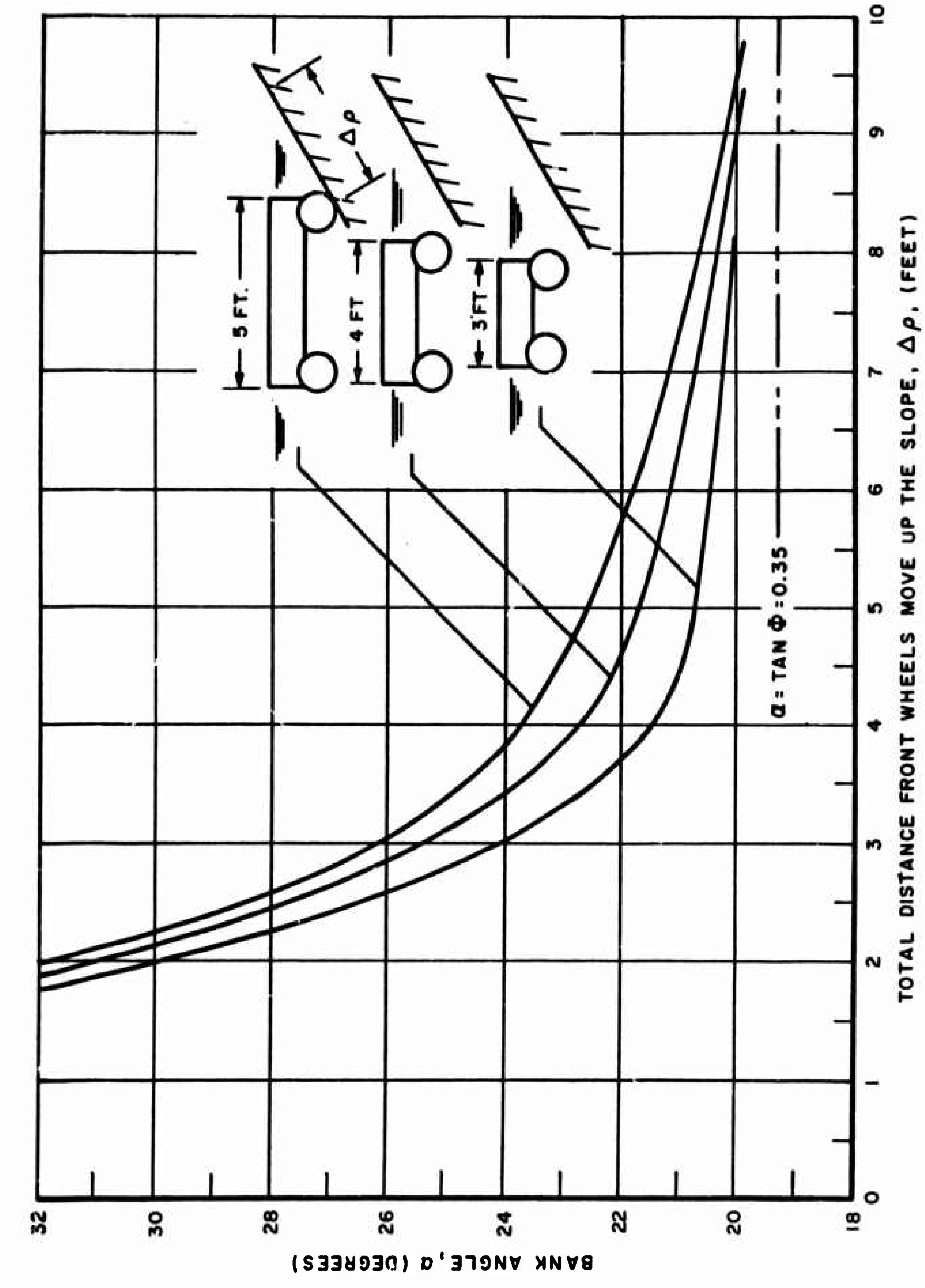


FIGURE 3. Effect of Vehicle Length on Bank Egress

from the propulsion unit would assist the longer vehicle for a greater distance and allow it to reach the stronger soil farther up the slope.

Of course the foregoing analysis is restricted to the limits set for the analysis; soil will be firm and will present negligible resistance. Exiting capability may decrease with length if soil resistance is significant, since other studies indicate that during exiting the front of the vehicle tends to carry a greater proportion of vehicle weight as the length of the vehicle is increased.* For example: axle loadings for a long, narrow, 8x8 model showed an approximately 100-percent overloading of the front axle during the exiting process. This means that, if soil resistance were a consideration, this overload on the front wheels might develop sufficient resistance to immobilize the vehicle.

The proportion of vehicle weight that will be carried by the front axle or axles during exiting is dependent on:

(a) Number of axles
(b) Location of axles
(c) Center of gravity of vehicle
(d) Characteristics of suspension system

An analysis of all of these parameters is worthy of separate study; it is, however, definitely beyond the scope of this preliminary parametric study.

EFFECT OF FREEBOARD

The performance of the vehicle with lower freeboard is, surprisingly, slightly better than that of the vehicle with higher freeboard (Fig. 4). There would be an obvious tendency for the vehicle with lower freeboard to swamp more easily, although a sealed hull would prevent this from becoming a factor. Careful examination of Fig. 4, however, reveals that the vehicles with lower freeboard first contact the bank at a deeper

---

*See Reference 14 and exiting study of XM453 presented later in this report.

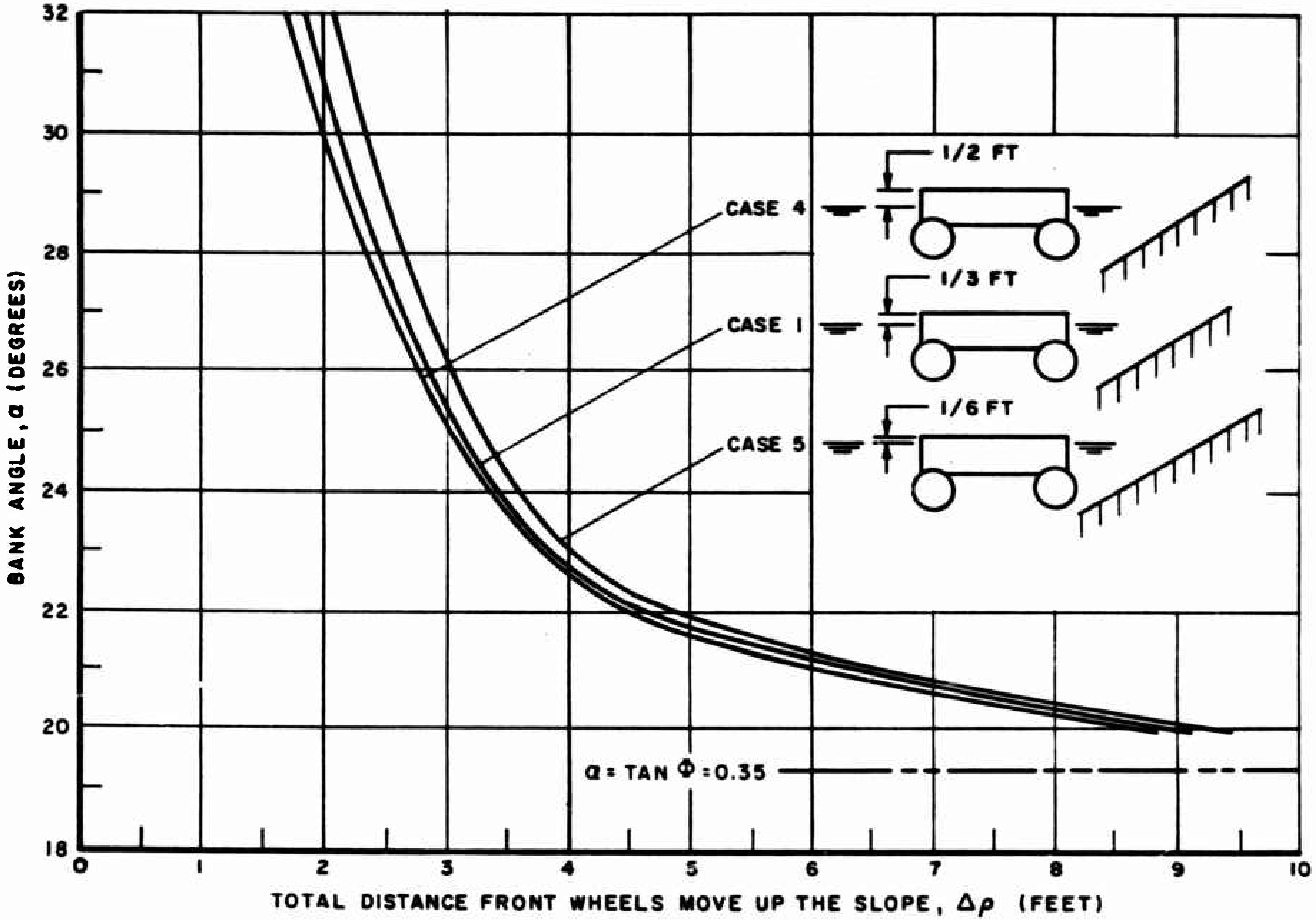


FIGURE 4. Effect of Vehicle Freeboard on Bank Egress

location. The value for $\Delta\rho$, therefore, begins from different points on the bank. When this fact is taken into consideration, and the actual distance above the waterline is calculated, the differences between configurations become negligible.

EFFECT OF CG LOCATION

Vertical CG location has little effect (Fig. 5). The performance of the vehicle with the higher CG is slightly better.

Changing the horizontal location of the CG, however, results in a complex relationship (Fig. 6) -- the forward CG location is best on the lower range of bank angles and the centrally located CG is best on the higher bank angles. The improvement in performance at lower bank angles, with a forward CG location, is apparently due to the increased load on the front wheels, which provides greater traction. At higher angles, the impact angle between the vehicle and the bank is increased to the point where the moment produced at the instant of impact has a "toe stubbing" effect, which causes the vehicle to pitch still farther forward and impedes progress up the bank. It must be noted, however, that the use of a soft soil in the simulation could completely reverse these trends, because an overloading of the front axle could cause early immobilization of a vehicle with its CG at a forward location. As in the case of the variations in freeboard, variations in LCG change the point of bank contact somewhat. This, however, does not materially change the results.

EFFECT OF CHANGES IN SUSPENSION-SYSTEM PARAMETERS

Over the ranges investigated, the effect of changes in suspension spring or damping rates was found to be insignificant. Therefore, no figures were prepared. The addition of soil properties and a non-uniform bank might produce different results.

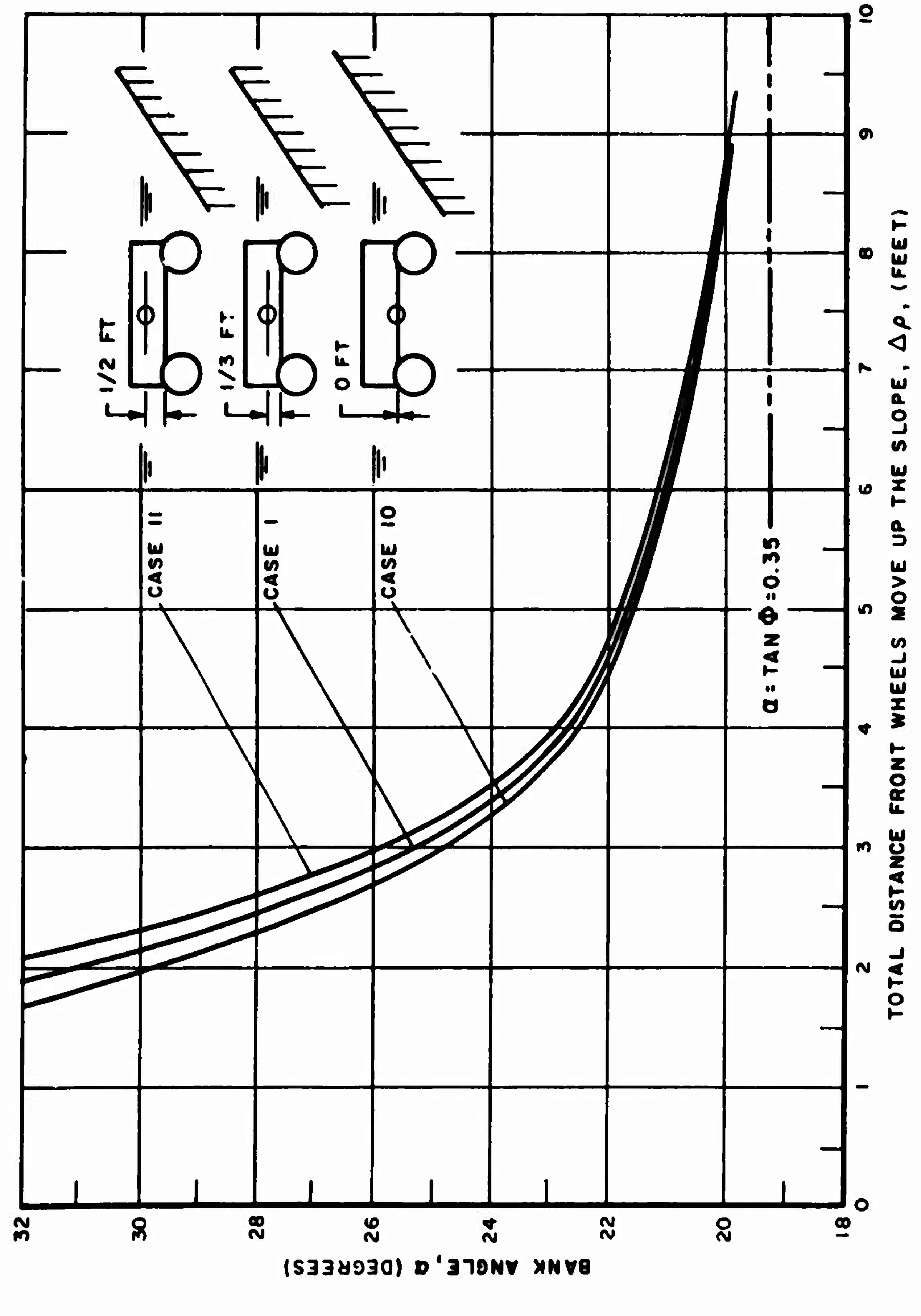


FIGURE 5. Effect of Vehicle Vertical CG Location on Bank Egress

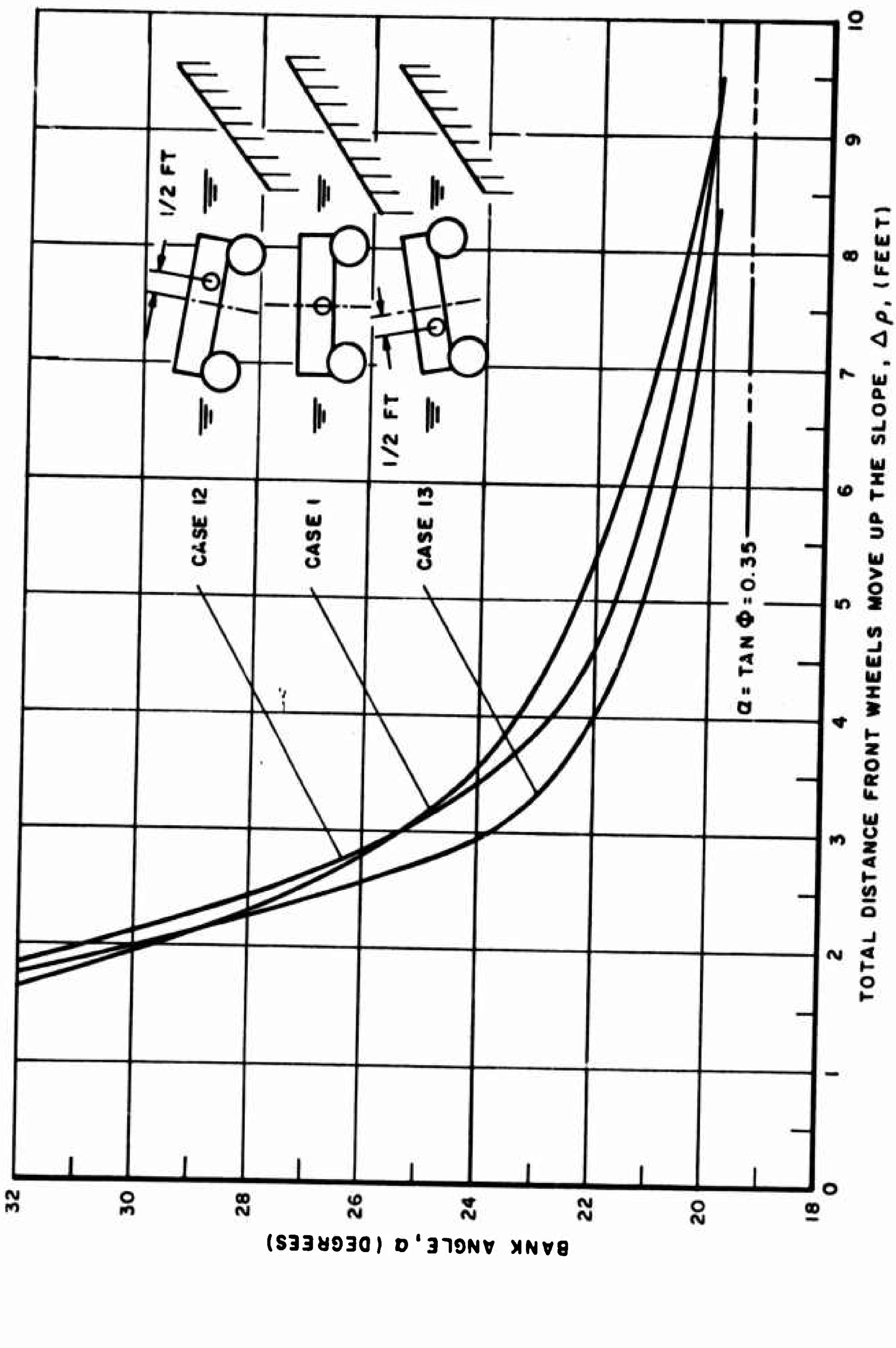


FIGURE 6. Effect of Vehicle Horizontal CG Location on Bank Egress

EFFECT OF INITIAL VELOCITY

The effect of initial velocity is pronounced (Fig. 7). There is an approximately linear relationship between the initial velocity and the distance the vehicle moves up the bank. This indicates that a simplified analysis which assumes a direct conversion of the kinetic energy of the initial motion to potential energy at the final height would be substantially in error, because such an analysis would yield a squared relationship.

EFFECT OF BANK FRICTION COEFFICIENT

The effect which the coefficient of friction has on slope is shown in Fig. 8. The effect is most pronounced at the lower bank angles. The distance the vehicle will travel up the bank goes to infinity as the coefficient of friction approaches the tangent of the bank angle.

COMBINED EFFECTS OF BANK FRICTION COEFFICIENT AND INITIAL VELOCITY

Because of the paramount influence that bank friction coefficient and initial velocity have on predicted egress performance, an additional parametric study was conducted to evaluate their combined effect. The results are plotted in Fig. 9, for the central case on a 20-deg bank.

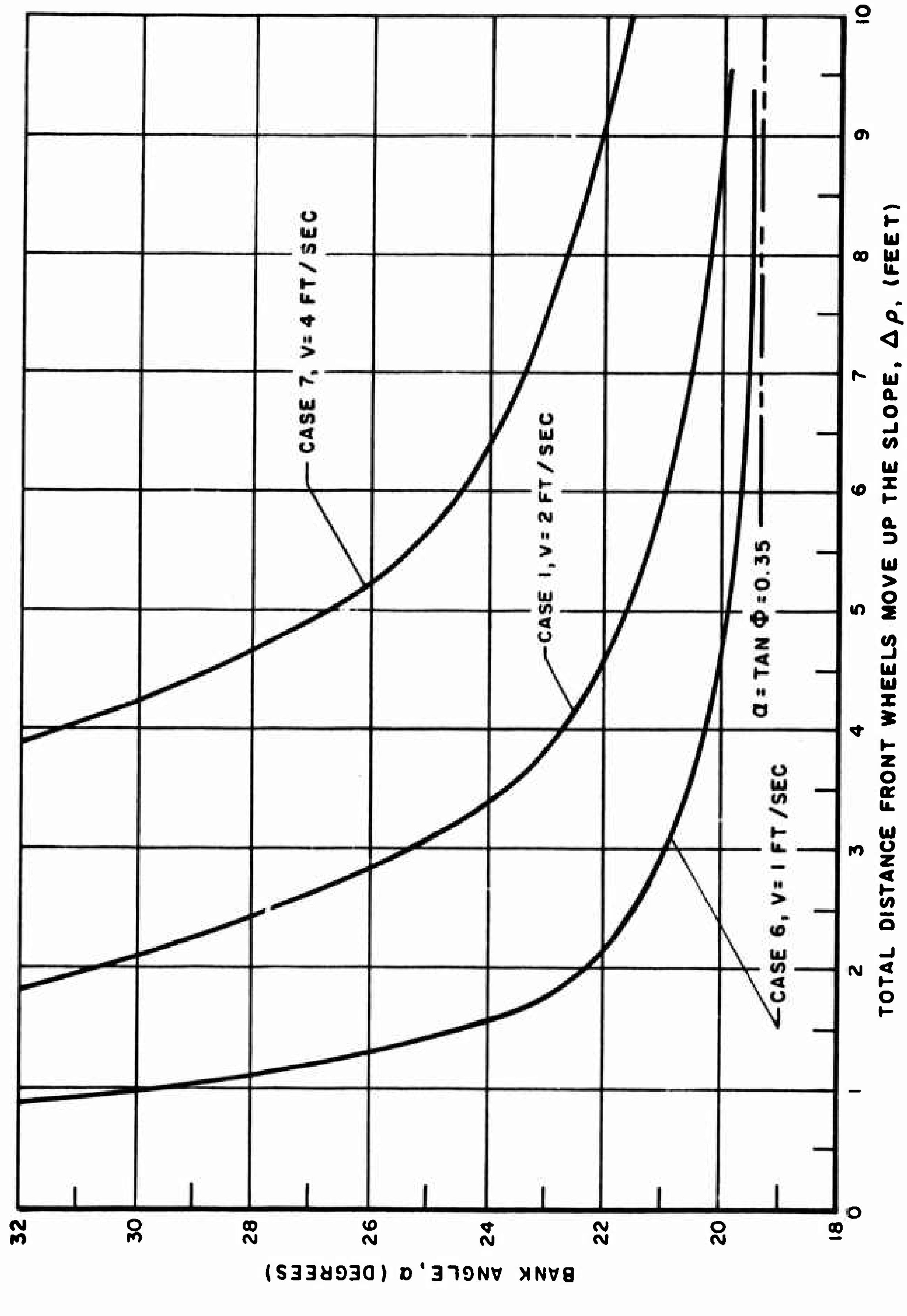


FIGURE 7. Effect of Vehicle Initial Velocity on Bank Egress

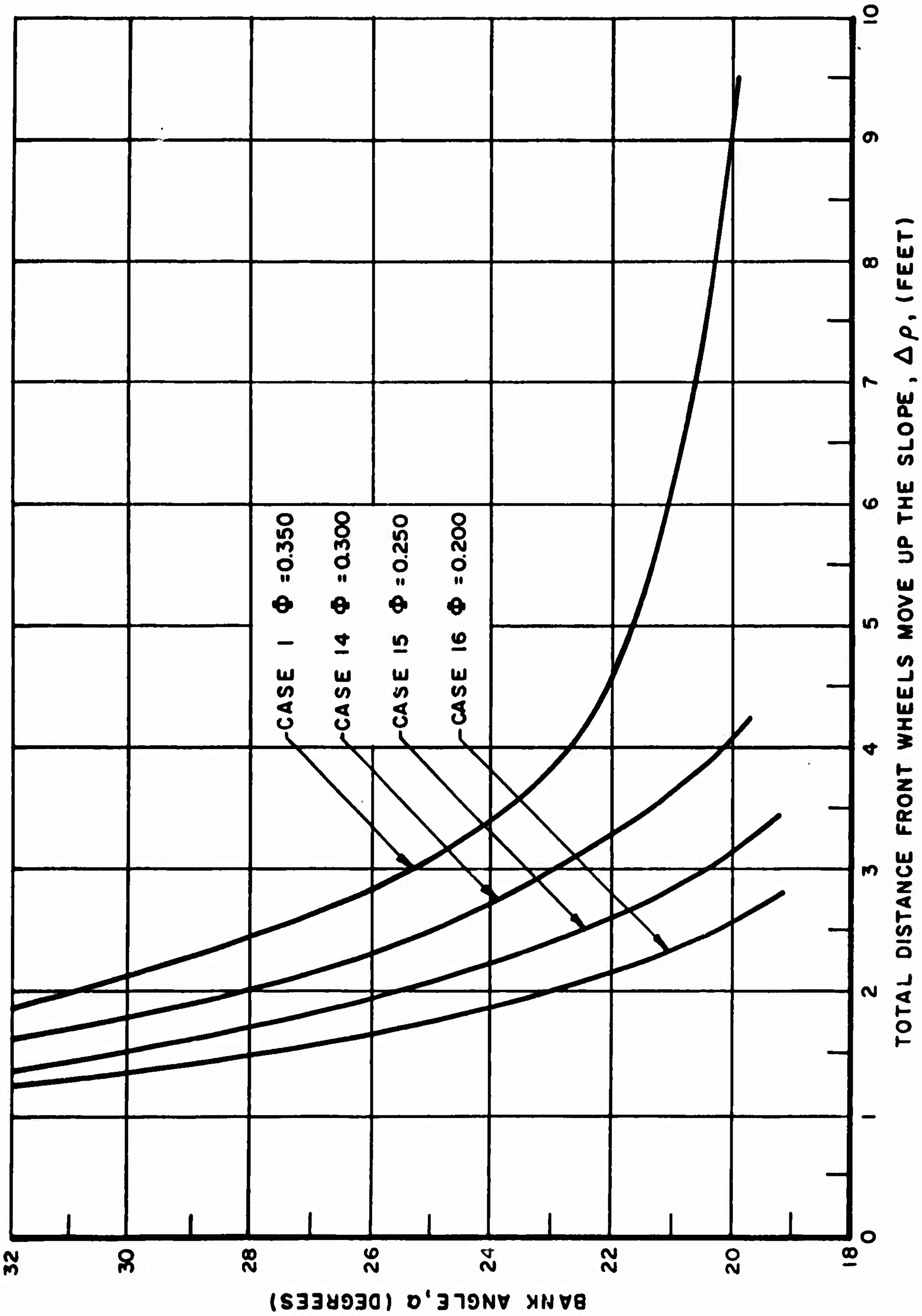


FIGURE 8. Effect of Coefficient of Friction on Bank Egress

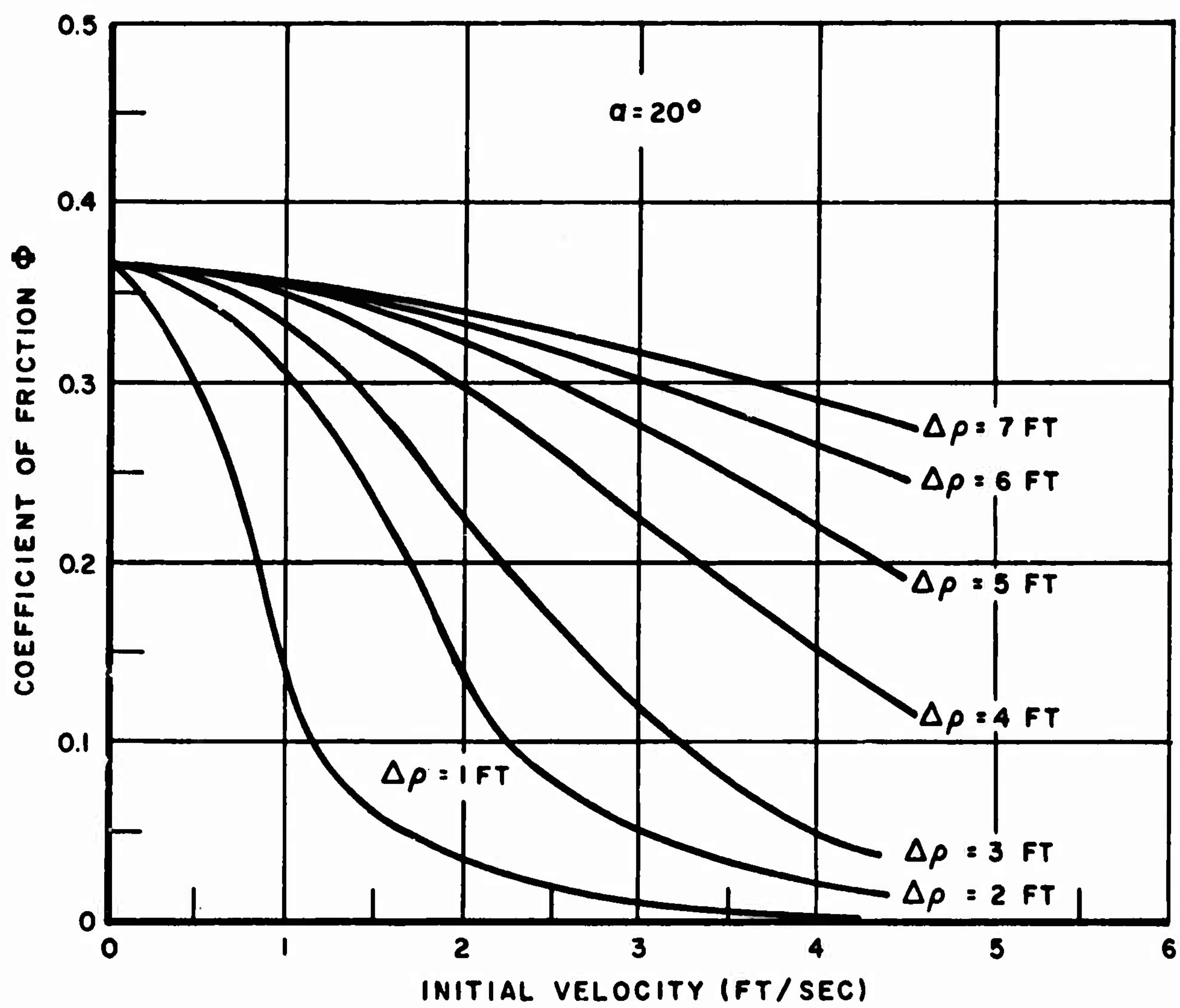


FIGURE 9. Combined Effect of Coefficient of Friction and Initial Velocity on Egress onto a 20° Bank

Chapter 3

VALIDATION

MODEL TESTS

An opportunity to validate the computer simulation arose when the University of Detroit conducted egress tests of a $\frac{1}{4}$-scale model of the 8x8, XM-453 floating truck in the river simulation facility at the Land Locomotion Division.[14] In that program, instrumented tests were conducted with the vehicle model egressing onto a hard aluminum surface inclined at angles in the range of 10 to 30 degrees, for both the self-powered and towed cases. Figure 10 shows the model and the test setup.

The vehicle model was towed or self-propelled up the bank from an initial floating position. The loading on the bank, the towing effort (when the vehicle was towed), and the vehicle trim angle were measured as functions of the distance the vehicle model moved up the bank. The starting point for the measurements was the initial contact point between the first wheel and the bank. The bank was suspended with force links, to measure the normal and tangential forces on the bank. Potentiometers were used to measure the trim angle of the vehicle and the distance it moved up the bank. A complete description of the tests and an analysis of results is given by Baker et al.[14]

COMPUTER SIMULATION

The computer program employed for this phase was essentially the same as the one discussed earlier. The few changes are noted below.

The simplified computer-model geometry consists of four rectangular boxes for the vehicle hull and four thick-walled circular rings for tires (Fig. 11).* These components were sized to match the model displacement

*The program is two-dimensional. Therefore only one half of the vehicle is used for the simulation.

FIGURE 10. Load-Measuring Ramp in the River Simulation Facility, Used to Measure Vehicle Exiting Performance and to Obtain Computer Simulation Validation (Shown with a 1/4 Scale XM-453, 8x8, 5-Ton, Cargo Truck Model)

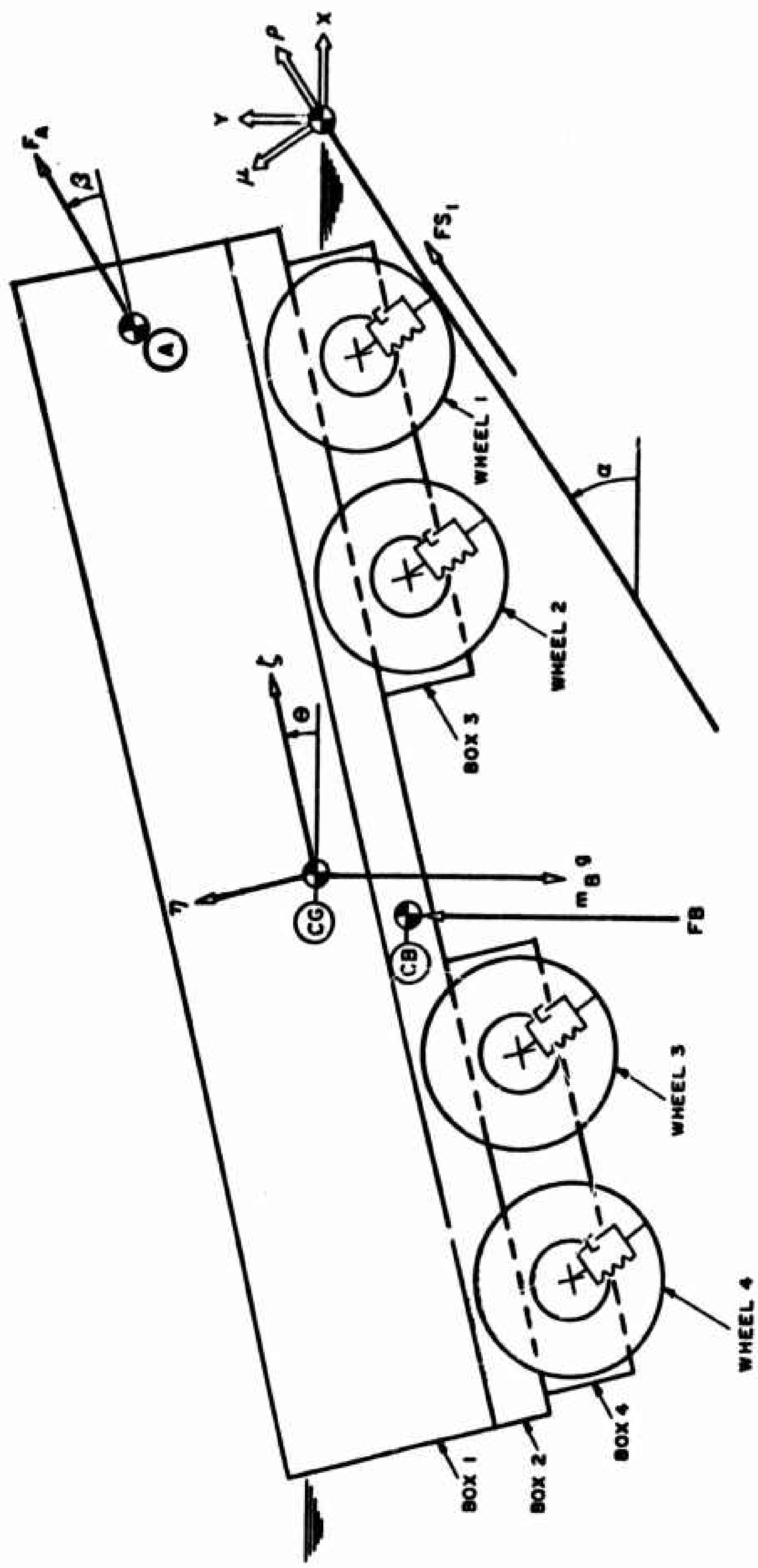


FIGURE 11. XM-453 Egress Model Simulation

properly. However, the variation in total buoyant force, with immersion and trim angle, differs slightly from that for the model, due to the simplified geometry employed. Axles were not included in the computer simulation. Neither the computer simulation nor the model had a suspension system. Tires were mounted on the model and simulated in the computer program.

Instructions for the use of the computer simulation have been presented by Worden, with the complete program.[23] The program is written in FORTRAN IV and was designed for the IBM 360/40 at the Stevens Institute of Technology.[24,25]

MATHEMATICS

The equations employed in the 4x4 simulation are used, basically, in the XM-453 simulation. Those which are slightly different are presented here.

Body Equations of Motion

The lack of a suspension system and the increased number of wheels changes the equations of motion slightly.

Since there is no suspension, we may let

$$m = \sum_{i=1}^{NB} m_i + \sum_{k=1}^{NW} m_k$$

$$m\ddot{X}_{CG} = F_A \cos(\theta + \beta) + \sum_{k=1}^{NW} (FS_k \cos\alpha + D_k \sin\alpha + RR_k \cos\alpha) \qquad (24)$$

$$m\ddot{Y}_{CG} = F_A \sin(\theta + \beta) - mg + \sum_{k=1}^{NW} (FB_k - D_k \cos\alpha + FS_k \sin\alpha + RR_k \sin\alpha) + \sum_{i=1}^{NB} FB_i \qquad (25)$$

$$I\ddot{\theta} = -\eta_A F_A \cos\beta + \zeta_A F_A \sin\beta + \sum_{k=1}^{NW} [\lambda_k FS_k + FB_k \zeta_k \cos\theta - FB_k \eta_k \sin\theta - D_k \zeta_k \cos(\alpha - \theta) - D_k \eta_k \sin(\alpha - \theta)]$$

$$+ \sum_{i=1}^{NB} \left[\zeta_{CB_i} FB_i \cos\theta - \eta_{CB_i} FB_i \sin\theta\right] \tag{26}$$

In the above equations for the XM-453 (NW = 4), the rolling resistance for the tires is equal to 0.06 the normal force, and λ_k is the length of the deflected tire from the axle to the ground contact point ($\lambda_k \leq r$).

Tire Forces

$$D_k = C_k \dot{\lambda}_k + K_k (\lambda_k - r) \quad ; \quad D_k \leq 0 \tag{27}$$

Tire Buoyancy

$$FB_k = \gamma \xi_t \ (A - B) \tag{28}$$

where A and B are as defined below:

CASE 1. Tire Completely Submerged

$$A = \pi r_t^2$$

$$B = \pi r_r^2 \tag{29}$$

CASE 2. Waterline Between Top of Rim and Top of Tire

$$A = r_t^2 \left[\cos^{-1} \frac{Y_k}{r_t} - \frac{Y_k}{r_t} \sqrt{1 - \left(\frac{Y}{r_t}\right)^2}\right]$$

$$B = \pi Y_r^2 \tag{30}$$

CASE 3. Waterline Between Top and Bottom of the Rim

$$A = \text{as in Case 2}$$

$$B = r_r^2 \left[\cos^{-1} \frac{Y_k}{r_r} - \frac{Y_k}{r_r} \sqrt{1 - \left(\frac{Y}{r_r}\right)^2} \right] \tag{31}$$

CASE 4. Waterline Between Bottom of Rim and Bottom of Tire

$$A = \text{as in Case 2}$$

$$B = 0 \tag{32}$$

CASE 5. Tire Out of Water

$$A = B = 0 \tag{33}$$

Tire-Traction Equation

When tire is in contact with the ramp,

$$FS_k = \Phi D_k \tag{34}$$

COMPARISON OF MODEL-TEST RESULTS WITH COMPUTER SIMULATION

Figures 12 through 16 are plots of the performance predictions of the "Egress Computer Program" and the published test results.[8] The bank angles for which computer predictions are made are 10.3, 15.2, 20.8, 25.6, and 29.9 degrees (they match those for the University of Detroit model tests). Examination of these figures shows that the "Egress Computer Program" closely predicts both the trends and the magnitudes of the test results.

Figures 12A and 12B compare the towed and self-powered tests. Curve ABC is a plot of the total normal force (D) of all the wheels in contact with the bank versus the distance (ρ) that the front axle has moved up the bank; curve ABD is a plot of magnitude and location of the resultant normal force from all wheels in contact with the bank, both measured from the point where the front wheels initially contact the bank. Consequently, the front-axle-location and the normal-force-location curves are coincident (portion AB of the curve) until the second axle comes in contact with the

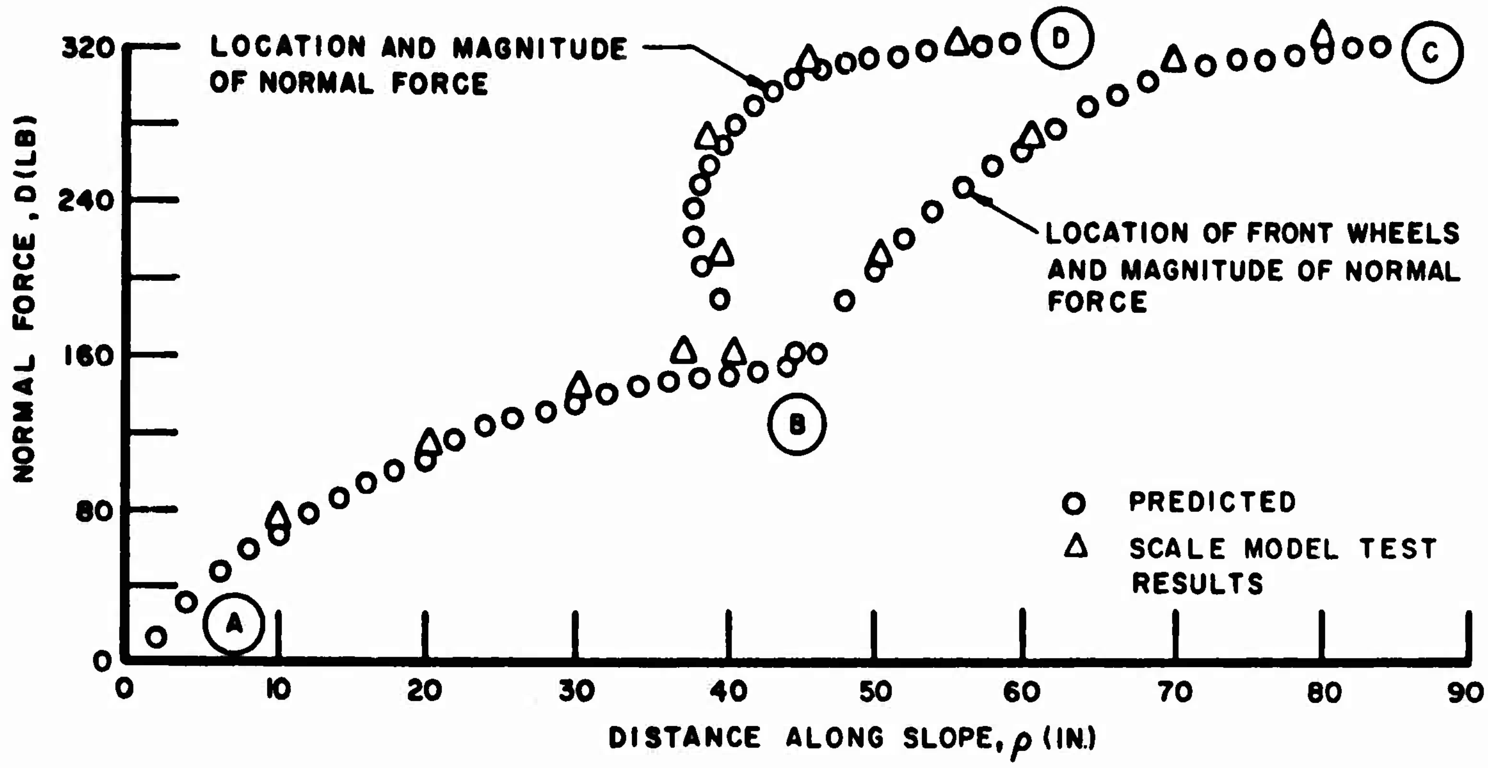


FIGURE 12A. Comparison of Computer Simulation and Scale-Model Tests for Towed Performance on a 25.6-Deg Slope

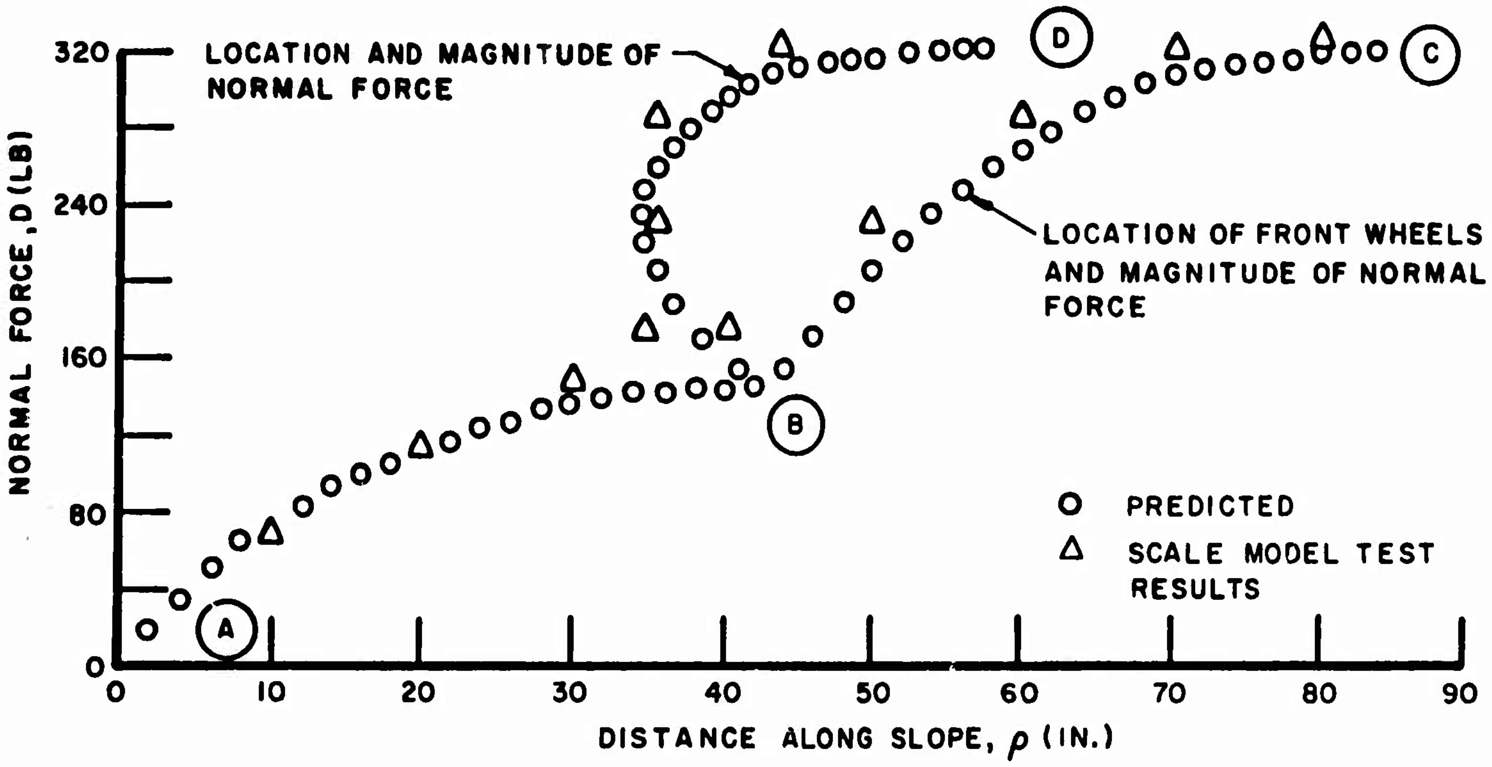


FIGURE 12B. Comparison of Computer Simulation and Scale-Model Tests for Self-Propelled Performance on a 25.6-Deg Slope

bank. Figures 12A and 12B show that the location of the normal force remains relatively constant as the second, third, and fourth wheel engage the bank in rapid succession and the vehicle weight becomes more evenly distributed.

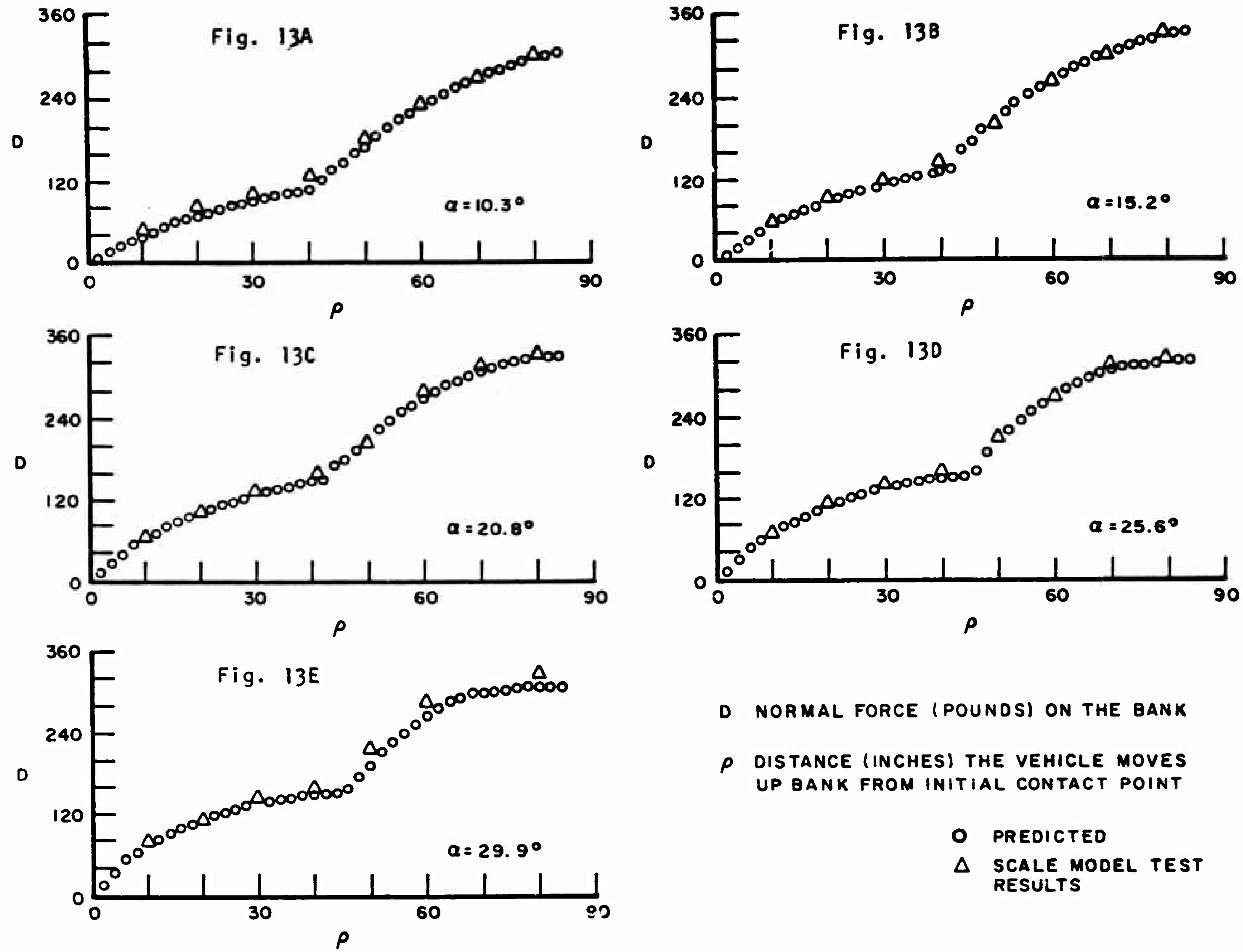
Figures 13A through 13E are plots for the normal force (D) versus the location of the front axle (ρ) for five bank angles. Predicted values and scale-model performance are shown for each bank angle. All plots are for towed performance only.

Figures 14 and 15 show the assist force required to take the vehicle out of the water. In these curves, dimensionless parameters have been used to represent the gross towing force and the net towing force versus the distance traveled up the bank from the initial contact point. Dimensionless parameters are used to allow extrapolation of the simulation results to other analogous vehicle configurations. Figures 14A through 14E are plots of the dimensionless assist-force coefficient F_A/mg versus the dimensionless bank-distance parameter ρ/L for various bank angles. In Figs. 15A through 15E the gross towing force is reduced by the level-ground rolling resistance of the vehicle, to give the net towing force. Figures 16A through 16E show the vehicle trim angle, θ versus ρ/L.

DISCUSSION OF RESULTS

Correlation of the data presented in Figs. 12 through 14 is considered excellent. The small variation existing in some of the curves can be attributed to experimental error, to uncertainty in the data reduction, and to the simplifications employed in the computer simulation. None of these appears to be significant.

Correlation between the vehicle trim angle (θ) and the other measured values does not match as well as the load data. The main reason for this is that the trim measurement on the model was relatively poor as compared with the accuracy of the other measurements. The trim was measured to $\neq 1$ degree, which represents an accuracy of approximately 7 percent of the maximum reading. On the other hand, the final total load on the ramp varied less than $\pm 1\frac{1}{2}$ percent from the gross model weight.



D NORMAL FORCE (POUNDS) ON THE BANK

ρ DISTANCE (INCHES) THE VEHICLE MOVES UP BANK FROM INITIAL CONTACT POINT

O PREDICTED

Δ SCALE MODEL TEST RESULTS

FIGURE 13 (A-E). Comparison of Computer Simulation and Scale-Model Tests for Towed Performance on Slopes of 10.3, 15.2, 20.8, 25.6, and 29.7 Degrees

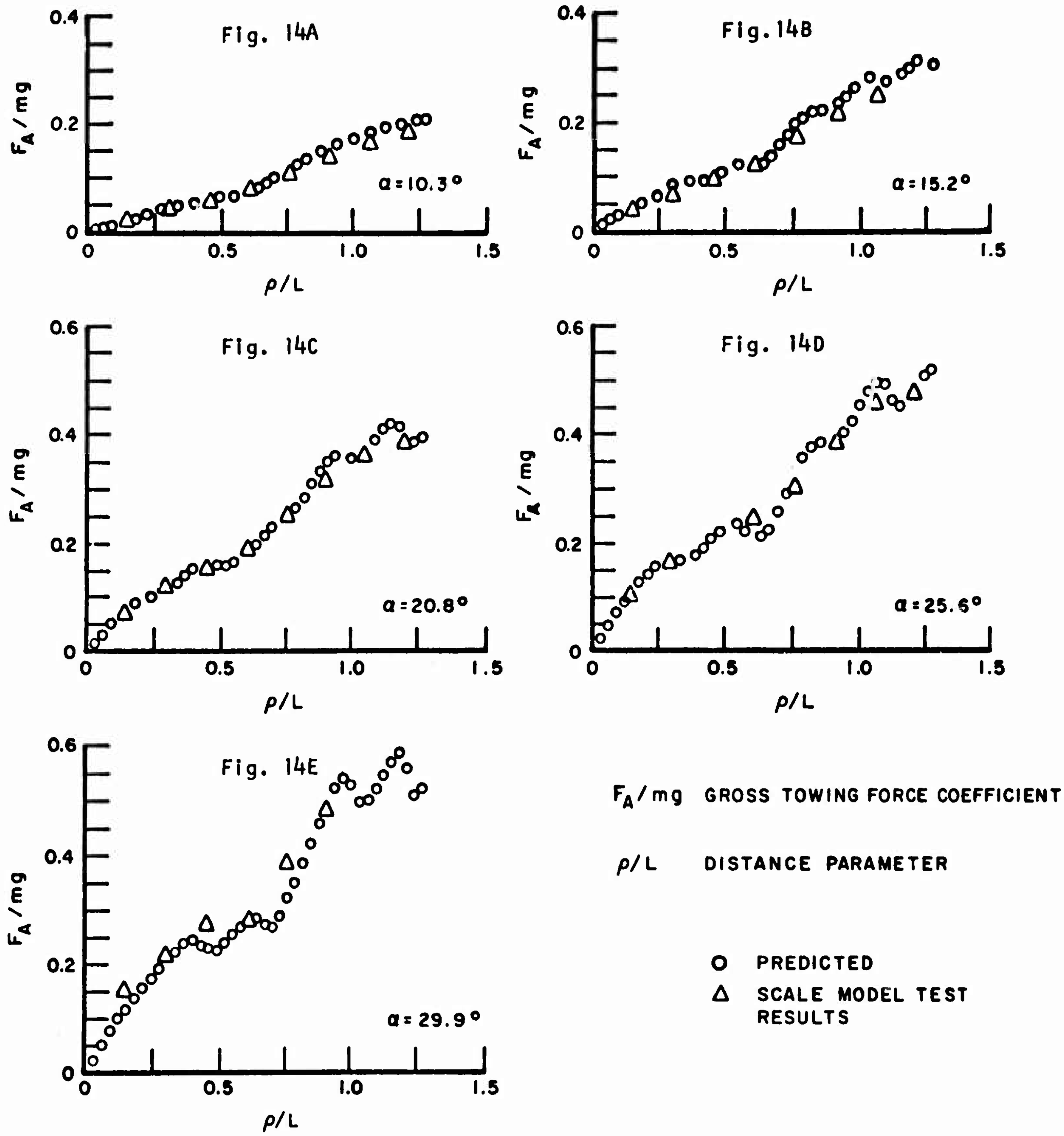


FIGURE 14(A-E). Comparison of Computer Simulation and Scale-Model Tests for the Dimensionless Gross Assist Force Coefficient Vs. Dimensionless Distance Parameter

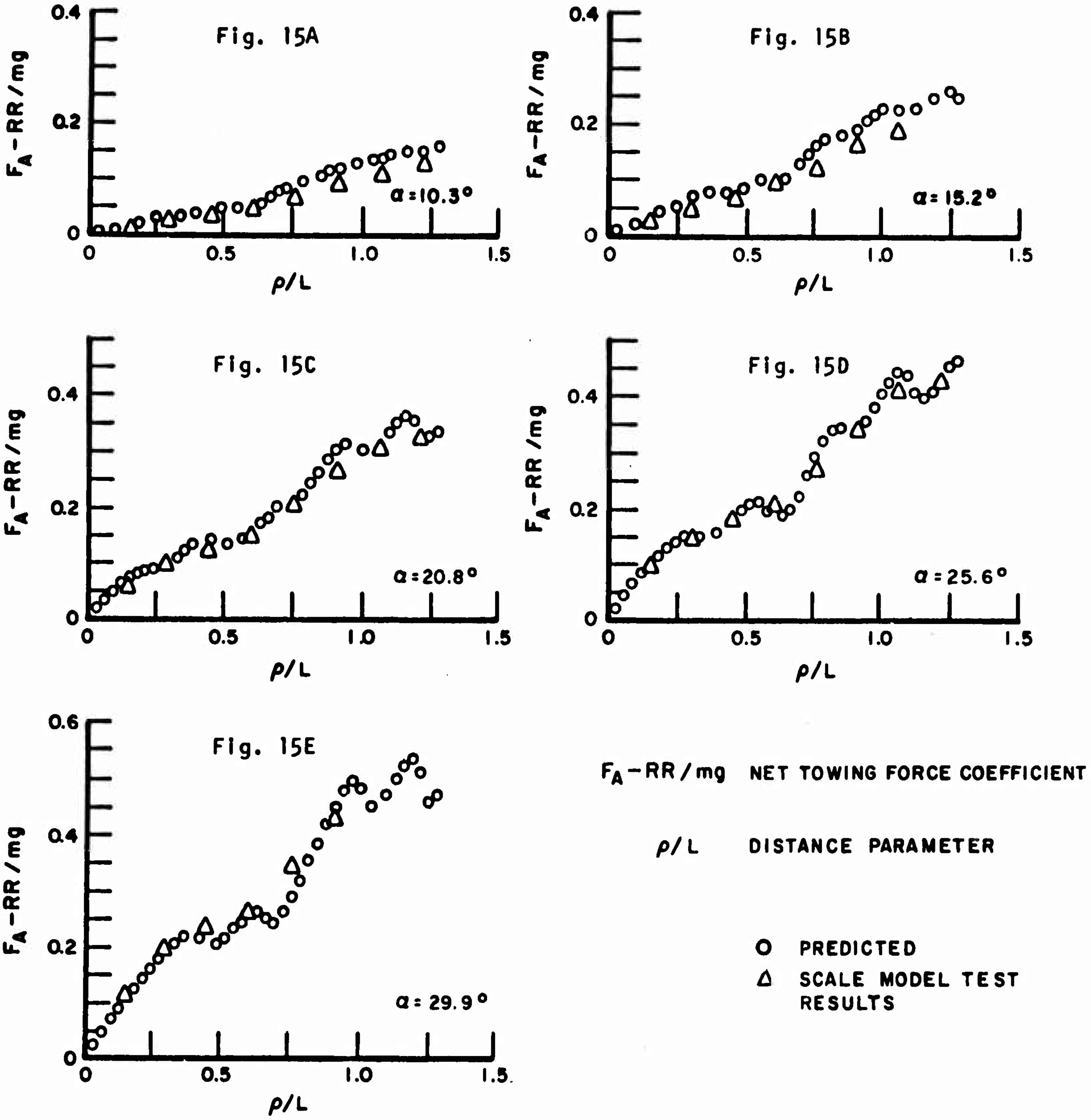


FIGURE 15(A-E). Comparison of Computer Simulation and Scale-Model Tests for the Dimensionless Net Assist Force Coefficient Vs. Dimensionless Distance Parameter

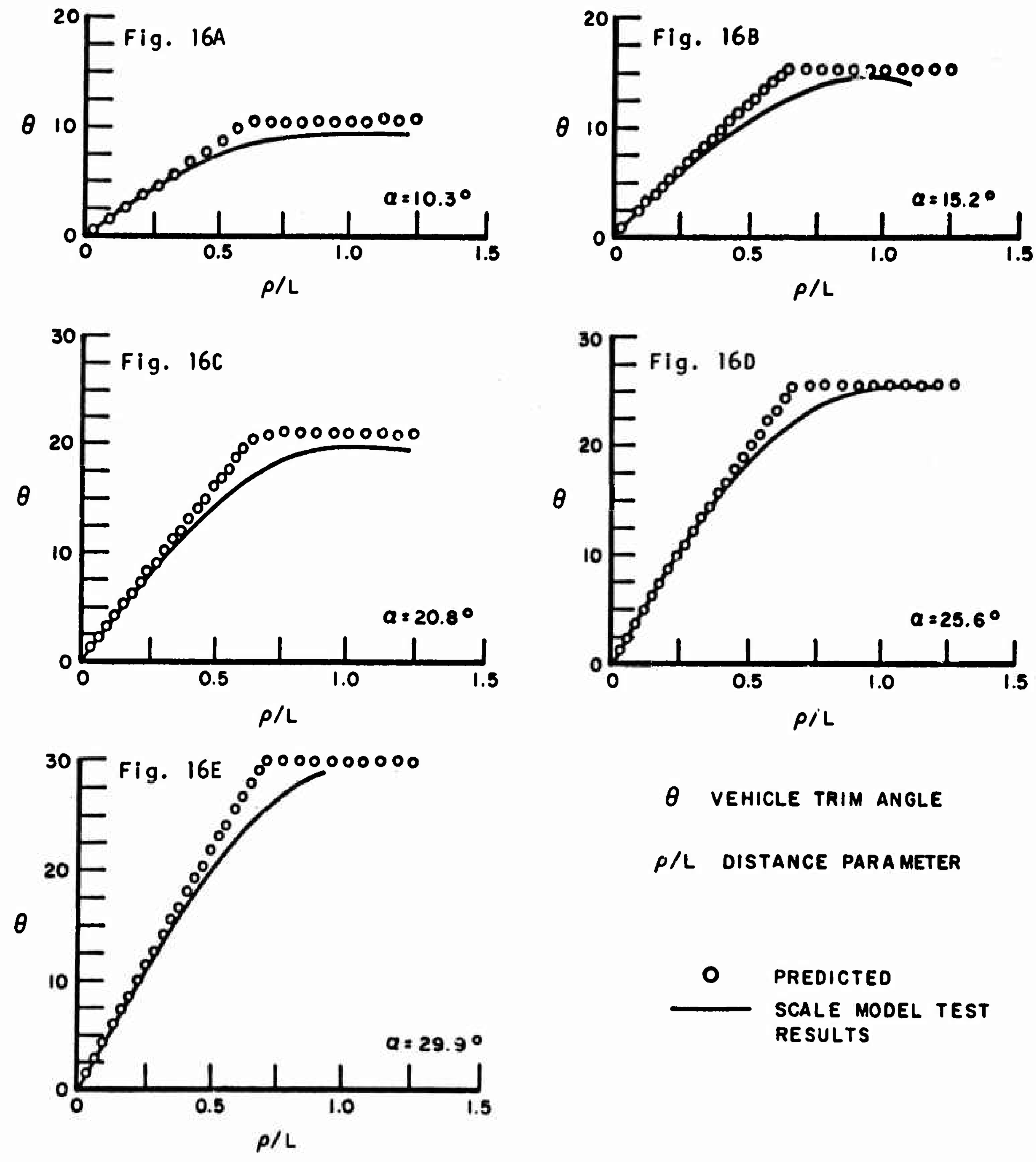


FIGURE 16(A-E). Comparison of Computer Simulation and Scale-Model Tests for Vehicle Trim Angle Vs. Dimensionless Distance Parameter

CONCLUSIONS

The fact that the simulation model could be used for the parametric study, wherein the output was distance traveled up the bank, and for the correlation study, wherein the output was wheel-loading on the bank, indicates that the model is flexible.

The objectives of the parametric study -- to make the egress computer program operational and to derive an insight into the influences which some of the major design parameters have on performance -- were met.

The correlation study validated the egress computer program and suggested ways of modifying the program to solve specific problems.

RECOMMENDATIONS

The parametric study should be expanded to include --

(1) A series of generalized wheeled-vehicle types such as 4x4, 6x6, 8x8, and 10x10 vehicles in both conventional and articulated versions.

(2) A series of generalized tracked-vehicle types in both conventional and articulated versions.

(3) A series of soil conditions, ranging from a firm soil with high internal friction and low cohesion.

(4) More generalized bank conditions with compound slopes and steps.

(5) A determination of the value of an assist force from "a self-recovery device," for a vehicle exiting on slopes that the vehicle could not normally negotiate under its own power.

The correlation study should be continued to include a tracked model (for which test data is now available), and at least one full-scale vehicle (for which test data should be available in the foreseeable future).

The results of all of these studies should be assembled into a design guide of handbook format.

ACKNOWLEDGEMENTS

This study was sponsored by both the U. S. Army Tank-Automotive Command and the Department of Defense THEMIS Program. The cognizant TACOM program engineer was Mr. R. Gay, whose interested cooperation, collaboration, and support in this very vital area is appreciated. The computer work was conducted on the IBM 1130 computer of Wilson, Nuttall, Raimond Engineers, Incorporated. Mr. C. J. Nuttall, Jr., the president of that firm, provided invaluable advice and support in many other areas in which he is expert. The programming was done by Mr. M. P. Jurkat of Davidson Laboratory.

APPENDIX

I. COMMENTS ON ARMORED AMPHIBIANS

Because of its quaintness and simplicity of style, the following translation of a Russian article on armored amphibians, by P. Brukhal,[26] is presented below as a bonus for those who have had the fortitude to read this far. It is entitled "Armored Amphibious Reconnaissance Vehicle."

> Soon summer will be here. Once again the grass will part and water rush under my armored reconnaissance vehicle. Right now we must prepare it for its long trips.
>
> I always begin this work by checking assemblies and tanks which need greasing. If necessary I fill them up. Then I inspect all remaining assemblies and components.
>
> I pay particular attention to the braking system. In case of necessity I add fluid to the master brake cylinders. Once the brakes failed on Pvt Tomin. Fortunately, this occurred on flat ground and at a relatively low speed. The reason was a simple one: fluid had leaked out of the cylinder for the right front wheel.
>
> Inspecting the water-jet engine I check to see how the baffle opens and closes. Then I see whether there are leaks from the water-jet drive casing, and whether there is enough oil. I check the cables carefully. Pvt Korvanyy was driving once when the baffle would not open fully due to weak cable tension.
>
> In crossing rivers, before the vehicle enters the water, I always check to see how solidly the plugs are in the bottom of the vehicle and whether or not the water drain is closed.
>
> Sometimes inexperienced drivers forget to raise the wave shield and put 1.0-0.75 kg/cm^2 in the tires. The first error is immediately obvious in the water -- water begins to pour into the vehicle. The second is more complicated. Some people are surprised: why did their vehicle get stuck at the bank when the others had no problem at all? The fact is that with higher pressure in the tires their traction surface is

reduced and thus the force of traction is poorer.

I enter the water in first or second gear, opening the water-jet engine baffle and switching it on. The speed should not exceed 10-12 km/hr. As soon as the vehicle touches the water I shift the gear lever into neutral. In the water I immediately look to see whether there are any leaks.
Pvt Dzyatko once forgot to close the water drain valve, and he did not notice the water immediately. The exercise had to be terminated, and if the shore had been further off the outcome might have been worse.

Under wind conditions I try to hold the vehicle into the waves and to go at maximum speed -- this guarantees maximum maneuverability. Before a large wave I reduce speed to soften the impact. If the viewports are unusable due to spray, I conduct observations through the periscope contained in the view instrument package.

Water turns present some difficulty for inexperienced drivers. Amphibious vehicles should be turned with the front wheels just as on dry land. But one should bear in mind that in water the turn is somewhat delayed. For a sharp turn I throttle down and close the water-jet engine baffle, then move the baffle control lever forward for a right turn and back for a left turn, increasing engine speed.

Once I drove my vehicle through an old river bed covered by water plants and mud. They clogged the grating of the intake sleeve on the water-jet engine. In order to clean it out I switched to reverse for two or three minutes in the drive selection box. Once our vehicle came onto a shallow spot and the wheels touched solidly, it was impossible to move the vehicle using only the water-jet engine. I tried both axles, but that did not help. I tried to shake the vehicle loose, switching on forward and reverse alternately. For reverse I throttled back and closed the water-jet engine baffle, then moved the baffle lever to full front position. After three or four minutes the vehicle disengaged itself.

For leaving the water I usually choose a gently sloping bank with solid ground, without rocks or snags. Last summer I had difficulty bringing the vehicle on shore across a silty bottom -- the wheels stuck and skidded. Now I shall attempt not to repeat such a mistake. A sticky bottom can be determined by lack of current and presence of water plants.

I try to direct the vehicle perpendicular to the shore line -- this reduces the possibility of sudden slips and wheel skids. Approaching the bank, it does not hurt to pick out ahead of time a tree or stump which in case of necessity can

be used to anchor the winch cable. Experience has shown that one should not stop until the wheels are completely out on solid ground.

After completion of an exercise the vehicle should be carefully inspected and serviced. Once Pvt Subochev did not notice oil leaks. It is a good thing this was caught at the check point. Otherwise this would have caused the crankshaft bearings to burn up.

I check particularly carefully the steering wheel clearance, the pins of the steering gear stays, brake operation, as well as condition of the springs and shock absorbers. Finally I grease everything that needs it.

II. WATER OBSTACLE CROSSING TECHNIQUES

Below is an extract from an article in the March-April 1967 issue of Armor, by Major Serventus T. Ashworth, III. It describes a few crude but effective techniques employed in Vietnam.

Since the major obstacle to M-113 movement is the numerous irrigation canals and rivers, various techniques have been developed locally to get the M-113's quickly across. The initial reconnaissance and selection of the crossing sites (normally two per troop) determines the technique to be used. A major consideration is the trafficability of the bank at the obstacle departure point. It must provide firm traction for the pulling vehicles to tow all the vehicles in the unit out of the water. Satisfying this requirement often results in the departure point being up or down stream from the entrance point. The influence of the tides must also be considered.

All canals in the Delta are affected by two high tides and two low tides in each 24 hour period. Due to the heavy accumulation of mud in the canal bottoms, otherwide easy crossings become extremely difficult during low tides.

Proven techniques include:

a. Run and jump method: Many small canals can be crossed by backing off from the bank and making a running approach. The forward motion, combined with the lift gained in leaving the near bank will carry the M-113 past its center of gravity on the far bank. Normally, no more than three vehicles should attempt this method. If none are successful then the "Push Board" method is used to complete the crossing.

b. Push board method: One M-113 in each platoon carries a section of aluminum balk approximately 5 meters long strapped on top. Normally this vehicle makes the initial crossing attempt on small canals. Once it bogs down the balk is slid off to the rear. Being aluminum it is light for its size and it floats. The cargo hatch is closed to prevent damage. The balk is braced either against the center of the lip running along the top of the stuck M-113's rear ramp or just above one of the tow hooks. A second M-113 is brought forward on the near bank to engage the balk against its front slope. On command, both tracks move forward in low gear, the rear one pushing until the front track is out on the far bank. At times, because of the poor trafficability along the banks, two pushing tracks in tandem may be used. Experience has shown this to be the maximum feasible number. Although the aluminum balk has proven to be the most satisfactory push board, almost anything of sufficient strength and length may be used (e.g. 6x6 planks, tree trunks).

c. "Choo-Choo Train" or "Daisy Chain": Once the initial M-113 is across a small canal, the cable of the next M-113 is hooked up and it is towed across. With two M-113's now on the far bank a third enters the canal and connects its cable to the two on the far bank. All the remaining M-113's on the near bank form a single line and hook up to the vehicle in front of them. After being hooked up, each M-113 backs off until there is no slack in the tow cables of the vehicles in the canal. Once all vehicles are connected, in train fashion, they move forward on command until the last one clears the canal.

Tow cables are an absolute must to movement in this terrain. In addition to the normal OEM cable, each M-113 should carry two, 3/4-inch cables slightly longer than the vehicle itself. The cables are prepared with a loop in each end secured by three cable clamps. In the normal carrying position these cables are attached, one each, to the left and right front tow hooks, draped back along the top of the vehicles and secured at the rear with a quick-release type tie down strap. A designated crewman of a vehicle requiring a tow, quickly disconnects the tie down and runs the free end forward to attach it to the towing vehicle. In addition to these cables, each troop normally carries two extra long cables (1/2" by 100') with the prepared loops in each end. Experience has shown that where the cable is attached to the towing vehicle is important. Normally the vehicle in the canal requires an up-and-out pull. To obtain this the cable is attached to the right or left lifting eye on the top rear of the towing vehicle. The quickest way to do this is to insert the cable loop over the eye and slide a track pin through the lifting eye to secure the connection. All vehicles carry extra pins for this and for linking together several cables quickly when they are required.

The requirement for equipment to enable an M-113 to winch itself out of a canal led to the locally-developed capstan and marine anchor kit. This consists of two aluminum drums which bolt to modified front drive sprockets of one M-113 per platoon, two rolls of heavy braided nylon rope and two commercial-type aluminum marine anchors. Full details on the minor modification required to install the kit and the stock number can be obtained by contacting Armor Command Advisory Detachment at USMACV Headquarters. Without these kits an M-113 unit loses considerable cross-country mobility in the Delta.

REFERENCES

1. U. S. Army Contract No. DA-30-069-AMC-789(T), 1 October 1965.

2. Davidson Laboratory Proposal 408, June 1965.

3. ROSSELL, H. E. and CHAPMAN, L.B., Principles of Naval Architecture, Vol. II. The Society of Naval Architects and Marine Engineers, New York, 1949.

4. LAMB, H., Hydrodynamics, Dover Publications, 1945.

5. BEKKER, M. G., Theory of Land Locomotion, University of Michigan Press, Ann Arbor, Michigan, 1960.

6. Staff of the Land Locomotion Laboratory, "Research Report No. 5," U. S. Army Tank-Automotive Command, 1958.

7. "Trafficability of Soils, A Summary of Trafficability Studies Through 1955," Waterways Experiment Station, TM 3-331, 1957.

8. Staff of the Land Locomotion Laboratory, "Research Report No. 6," U. S. Army Tank-Automotive Command, 1966.

9. LASSALINE, D. M., et al, "Pilot Study of River Frequency," TACOM Report 9647, March 1967.

10. SLOSS, D. A., et al, "River Magnitude and Frequency in the United States," TACOM Report 9784, November 1967.

11. SLOSS, D. A. and HANAMOTO, B., "River Magnitude and Frequency in Thailand," TACOM Report 9917, March 1968 (AD 839 444).

12. Foreign Technology Office, TACOM, "Barricade Widths of Bodies of Water in West Germany," Report FIO 825 (undated).

13. SLOSS, D. A., et al, "Analysis of Estimated River Exiting Performance," TACOM Report 9689, July 1967.

14. BAKER, W. G., et al, "Model Studies of Military Amphibious Vehicles Exiting from Rivers," TACOM Report 9945, March 1968 (AD 843 508 L).

15. BEKKER, M. G., Off-the-Road Locomotion, University of Michigan Press, Ann Arbor, Michigan, 1960.

16. LISTON, R. A., "Methods and Goals of the Mechanics of Off-the-Road Locomotion," SAE Paper No. 782A, January 1964.

17. MICKLETHWAITE, E. W. E., "Soil Mechanics in Relation to Fighting Vehicles," School of Tank Technology, Military College of Science (England), 1944.

18. REECE, A. R., "Problems of Soil Vehicle Mechanics," Land Locomotion Laboratory Report 97, March 1964.

19. WILLS, B. M. D., "The Load Sinkage Equation in Theory and Practice," Proc. Second International Conference of ISTVS, 1966.

20. FREITAG, D. R., "A Dimensional Analysis of the Performance of Pneumatic Tires on Soft Soils," Auburn University, Auburn, Alabama, June 1965.

21. NUTTALL, C. J., JR., WILSON, C. W., and WERNER, R. A., "One-Pass Performance of Vehicles on Fine-Grained Soils," WES Contract Report No. 3-152, Wilson, Nuttall, Raimond Engineers Inc., July 1966.

22. BEKKER, M. G., "Engineering Optimization of Terrain-Vehicle Systems," Land Locomotion Laboratory Report 133, February 1969.

23. WORDEN, GEORGE M., "A Computer Simulation of a 1/4 Scale, 8x8, XM-453 Truck Model Egressing onto a Hard-Surfaced Ramp," Davidson Laboratory Report 1242, October 1967.

24. IBM 1130 FORTRAN Language, IBM Systems Reference Library, Form C-26-5933-3, 1964.

25. RALSTON, A., "Numerical Integration Methods for the Solution of Ordinary Differential Equations." Mathematical Methods for Digital Computers, A. Ralston and H. S. Wilf, eds., John Wiley and Sons, N. Y., 1960.

26. FSTC 381-T65-515, U. S. Army Foreign Science and Technology Center Translation, November 1965.

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)
Davidson Laboratory, Stevens Inst. of Tech.
Hoboken, N. J.

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP

3. REPORT TITLE
STUDIES OF OFF-ROAD VEHICLES IN THE RIVERINE ENVIRONMENT
Vol. II. An Analytical Method for Egress Evaluation

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)
Final

5. AUTHOR(S) (First name, middle initial, last name)
D. Sloss, I. R. Ehrlich, and G. Worden

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
October 1969	49	26

8a. CONTRACT OR GRANT NO.
DA 30-069-AMC-789(T), DAAE-07-69-C-0356, and Stevens Internal Research Funds

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)
R-1393

9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT
No. 1

11. SUPPLEMENTARY NOTES
Department of Defense THEMIS Program

12. SPONSORING MILITARY ACTIVITY
U. S. Army Tank-Automotive Center
Warren, Michigan 48090

13. ABSTRACT

A limited computer-simulation model describing the dynamics of a swimming vehicle egressing from a stream is formulated. The effects of soil reactions, hydrostatic forces, suspension and tire dynamics, and auxiliary egress assist forces are considered. Results of a parametric study are presented for a four-wheeled, box-shaped vehicle egressing onto a hard, uniformly sloped bank. Length, freeboard, center of gravity, suspension spring and damping rates, initial velocity, and bank coefficient are varied in the analysis.

A correlation study, which validates the computer simulation model, is also described. Plots of normal wheel-loading versus distance up the bank, showing a comparison between the computer simulation and scale-model tests, are included.

Recommendations for a comprehensive parametric study and a correlation study with full-scale vehicles are made.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

UNCLASSIFIED

Security Classification

A-31408

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Vehicle Egress						
River Crossings						
Mobility						
Amphibians						
Simulation						
Floaters						
Swimmers						
Riverine Environment						
Off-Road Vehicles						

DD FORM 1 NOV 65 1473 (BACK)
S/N 0101-807-6821

UNCLASSIFIED
Security Classification

A-31409

DAVIDSON LABORATORY, Stevens Inst. of Tech.
Hoboken, N. J.

STUDIES OF OFF-ROAD VEHICLES IN THE RIVERINE ENVIRONMENT
Vol. II, An Analytical Method for Egress Evaluation

Research Report 1393 [Final]. Oct.1969. xvii + 49 p.

D. Sloss, I. R. Ehrlich, G. Worden.
DL Projects 3016, 3516, 3479 / 439, 408, 870.

For U.S. Army Tank-Automotive Center, Contracts DA 30-069-AMC-789(T), DAAE-07-69-C-0356, and Stevens Research Funds. Defense THEMIS Program.

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE; ITS DISTRIBUTION IS UNLIMITED. APPLICATION FOR COPIES MAY BE MADE TO THE DEFENSE DOCUMENTATION CENTER.

DAVIDSON LABORATORY, Stevens Inst. of Tech.
Hoboken, N. J.

STUDIES OF OFF-ROAD VEHICLES IN THE RIVERINE ENVIRONMENT
Vol. II, An Analytical Method for Egress Evaluation

Research Report 1393 [Final]. Oct. 1969. xvii + 49 p.

D. Sloss, I. R. Ehrlich, G. Worden.
DL Projects 3016, 3516, 3479 / 439, 408, 870.

For U.S. Army Tank-Automotive Center, Contracts DA 30-069-AMC-789(T), DAAE-07-69-C-0356, and Stevens Research Funds. Defense THEMIS Program.

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE; ITS DISTRIBUTION IS UNLIMITED. APPLICATION FOR COPIES MAY BE MADE TO THE DEFENSE DOCUMENTATION CENTER.

DAVIDSON LABORATORY, Stevens Inst. of Tech.
Hoboken, N. J.

STUDIES OF OFF-ROAD VEHICLES IN THE RIVERINE ENVIRONMENT
Vol. II, An Analytical Method for Egress Evaluation

Research Report 1393 [Final]. Oct. 1969. xvii + 49 p.

D. Sloss, I. R. Ehrlich, G. Worden.
DL Projects 3016, 3516, 3479 / 439, 408, 870.

For U.S. Army Tank-Automotive Center, Contracts DA 30-069-AMC-789(T), DAAE-07-69-C-0356, and Stevens Research Funds. Defense THEMIS Program.

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE; ITS DISTRIBUTION IS UNLIMITED. APPLICATION FOR COPIES MAY BE MADE TO THE DEFENSE DOCUMENTATION CENTER.

DAVIDSON LABORATORY, Stevens Inst. of Tech.
Hoboken, N. J.

STUDIES OF OFF-ROAD VEHICLES IN THE RIVERINE ENVIRONMENT
Vol. II, An Analytical Method for Egress Evaluation

Research Report 1393 [Final]. Oct. 1969. xvii + 49 p.

D. Sloss, I. R. Ehrlich, G. Worden.
DL Projects 3016, 3516, 3479 / 439, 408, 870.

For U.S. Army Tank-Automotive Center, Contracts DA 30-069-AMC-789(T), DAAE-07-69-C-0356, and Stevens Research Funds. Defense THEMIS Program.

THIS DOCUMENT HAS BEEN APPROVED FOR PUBLIC RELEASE AND SALE; ITS DISTRIBUTION IS UNLIMITED. APPLICATION FOR COPIES MAY BE MADE TO THE DEFENSE DOCUMENTATION CENTER.